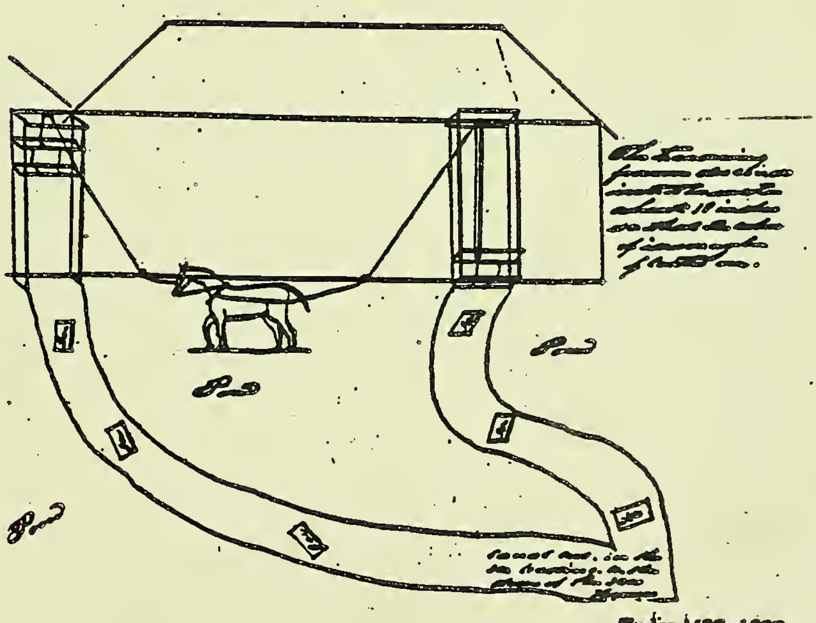
BOSTON ICE



Tudor MSS, 1827

[Circa 1981]

The City of Boston is attempting to explore the potential of utilizing ice in shaving cooling and refrigeration costs. In the 19th century, Boston was the leading exporter of ice to the world. Every continent unloaded the crystal blocks of Yankee cold at its docks. Today many buildings and complexes are utilizing the thermal storage capacity qualities of ice in shaving daily or annual peak loads. Boston currently has three water thermal daily storage systems in place. Although there is no installation in place which transfers loads on an annual basis or utilizes the latent heat capacity of ice or renewable energy of winters natural cold, we would like to explore in the confines of this grant the potentials of these three technologies. Although Boston's cooling days are about 1/9 of its heating degree days, there are enormous implications for the dense citys core and, possibly a revised renewal of the enormous 19th century ice export industry.

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This book was prepared for the Department of Energy's Appropriate Technology Program under grant #DE-FG41-80R110417

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Massachusetts Institute of Technology

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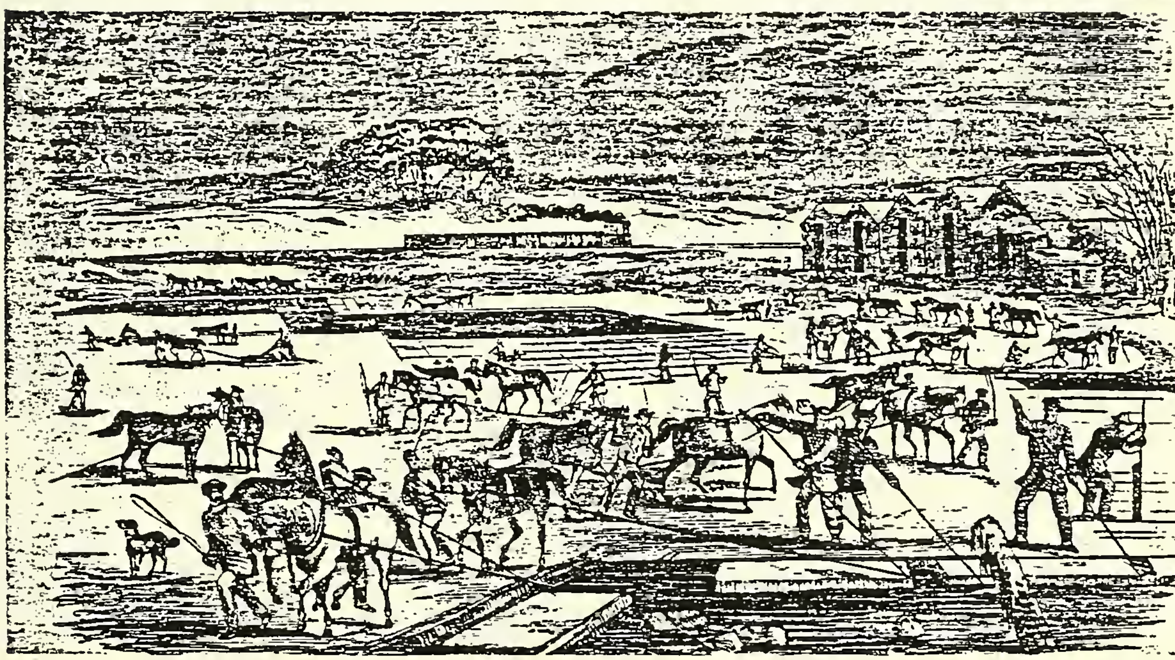
Douglas Ivers

HISTORY OF THE ICE INDUSTRY



Gleason's Drawing Room Companian, 1852

HARVESTING, MASSACHUSETTS, EARLY 'FIFTIES

Specially designed freight cars carried mid-century harvests from Fresh Pond and Spy Pond to Boston. Train is shown in background.

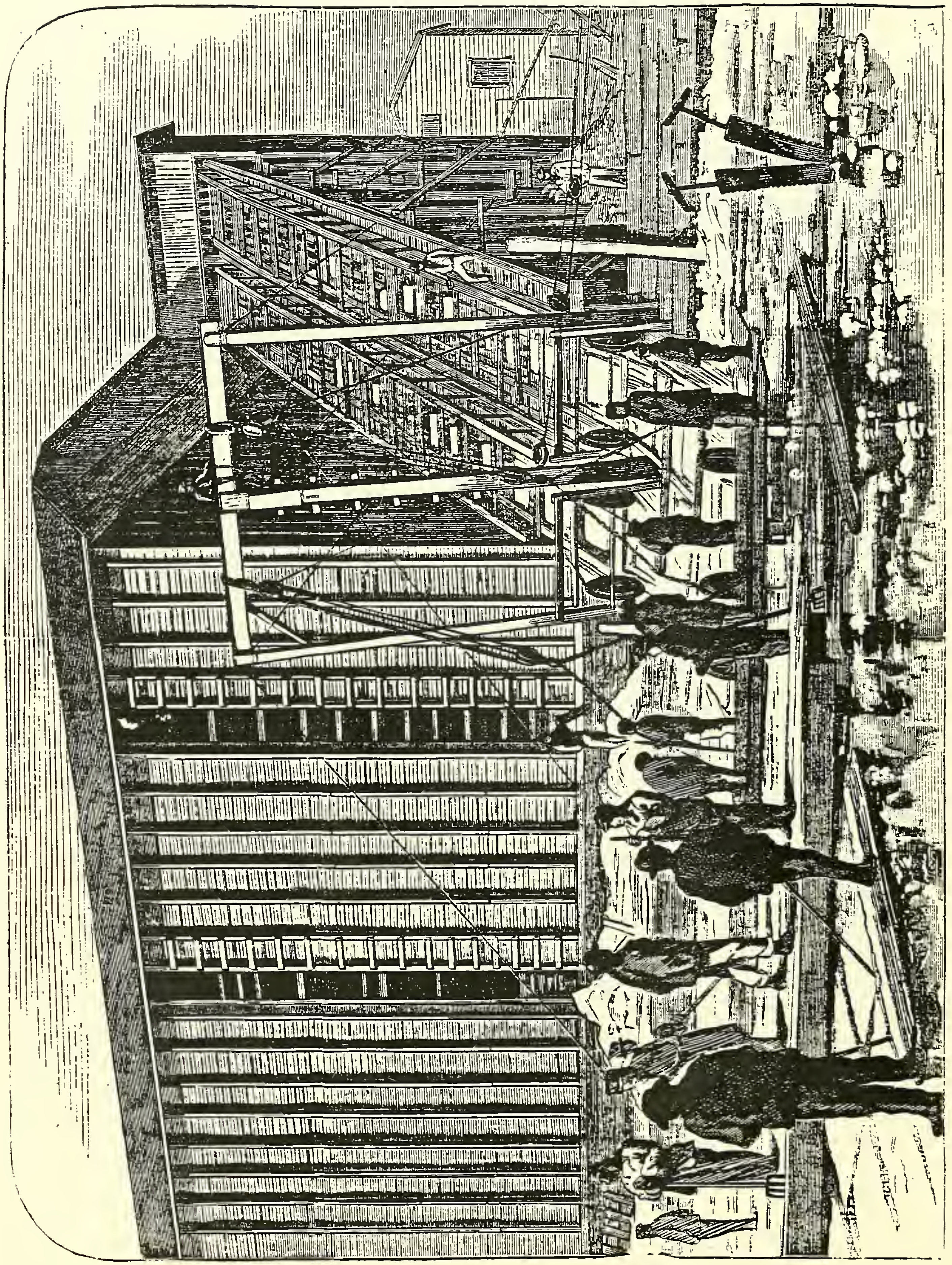
ICE HARVESTING ON THE HUDSON.

THE ICE INDUSTRY

Before the invention of mechanical refrigeration, the world functioned on passive space cooling and refrigeration with natural ice. Builders of the 18th and 19th century kept occupants comfortable throughout the summer with shading, ventilation, and thermal storage. Summer breezes were increased with appropriate openings, vents and breezeways while the hot sun was shielded by overhangs, shutters and landscaping. The more massive construction functioned as a heat sink both in summer and winter.

The biggest consumer of process cooling was the food industry which subsisted totally on the harvesting and storage of natural ice. Millions of tons serviced the refrigeration-car traffic, the cold-storage warehouses, breweries, meat packers and individual householders. As local ponds were needed for resevoirs or became contaminated, the ice companies would move to more remote, northern or higher locations. The northern part of this country provided the most abundant crop and the largest exporter in the world was the port of Boston. For years its profits exceeded those of other exports and the volumn culminated in 1856 at 146 thousand tons.

The techniques of harvesting and storing this natural commodity were developed to an extremely efficient and practical system. Labor was provided by farmers in their slack season. Equipment for chopping the ice was improvised from sawtooth sleigh runners 20 inches on center. By using one of the marks for the next run a set of parallel grooves were scored and then crossed at right angles with another set. As ice readily splits, tapping with a bar in the grooves provided cubes which were floated in a channel to the shore. Once out of the water the cubes were either stored in a hugh warehouse on the bank or shipped by rail to southern ports or to the shipyard for export. Among the many techniques developed for storing the winter cold were constructing pits and cellars underground or building extra thick, airtight construction or double walls with insulation such as straw, sandust, animal hair or tan bark between the layers. Drainage and venting were also highly evolved. So without our compressors and foams, even the smallest farmer was able to have refrigeration right on thru the summer.



GLOSSARY (A)

Frederick Tudor -

Largest exporter of Boston ice.

Nathaniel Wyeth -

Inventor of ice cutter - 1825.

"Whenham Lake Ice" -

Ice from lake in Massachusetts which had world wide reputation for quality and clearness.

"Boston Tongs" -

Commonly used tongs for handling ice which permitted holder to catch block low on the sides.

Pick -

Instrument for splitting ice.

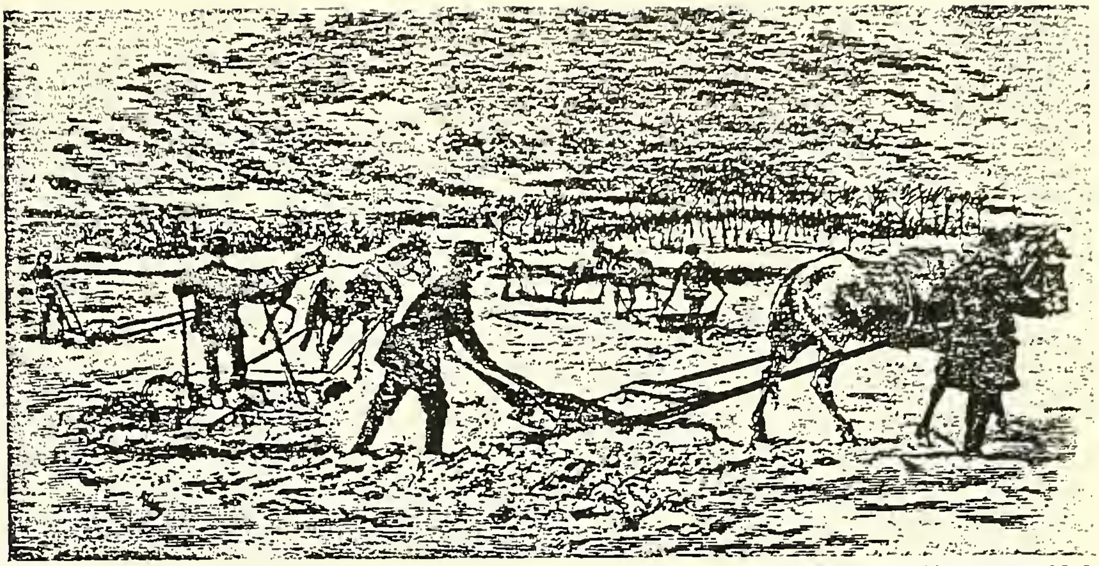
Ice Wagon -

Insulated wooden wagon for home ice delivery.

43. CANALMEN "FEEDING THE CHAIN," as loading the elevator was called, at Consumer's Village houses in January 1899. Note the skiff, far right, used as an icebreaker. It is apparent that these houses sat right on deep water, for the elevator does not run out into the river at all. There were no flats, hence the gangplank type staircase to get on and off the river (left background).

Where there was ice on every lag, the chain was said to be painted white. Especially when the ice was extra thick—it could be as much as 18"—the full chain would sometimes break and all the ice would slide back into the canal. When the men heard the chain snap and saw the ice coming, there was a grand exodus from that part of the canal.

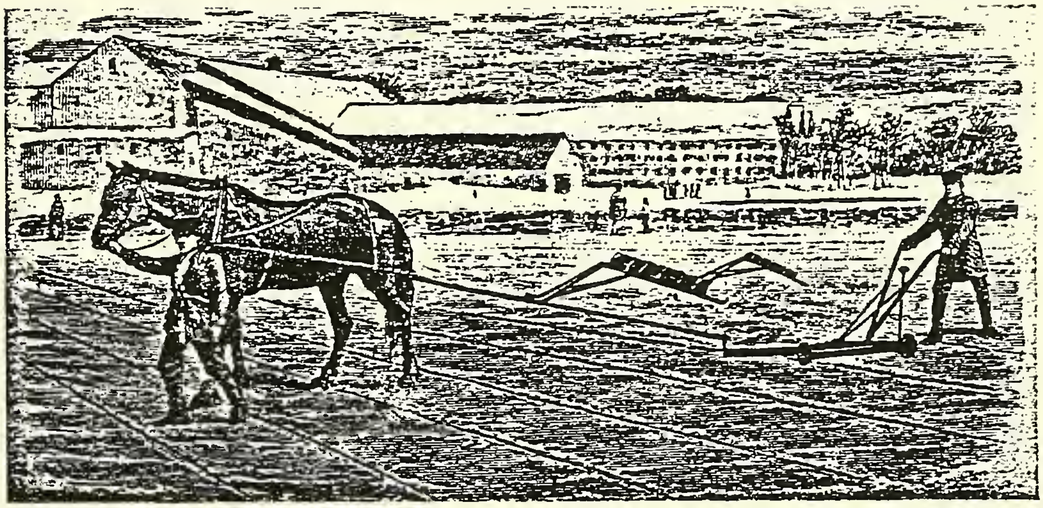
The ice houses took quite a beating and in many of the photographs we have collected their walls are being propped as here.



Scribner's Monthly Magazine, 1875

SCRAPING, FRESH POND, CAMBRIDGE

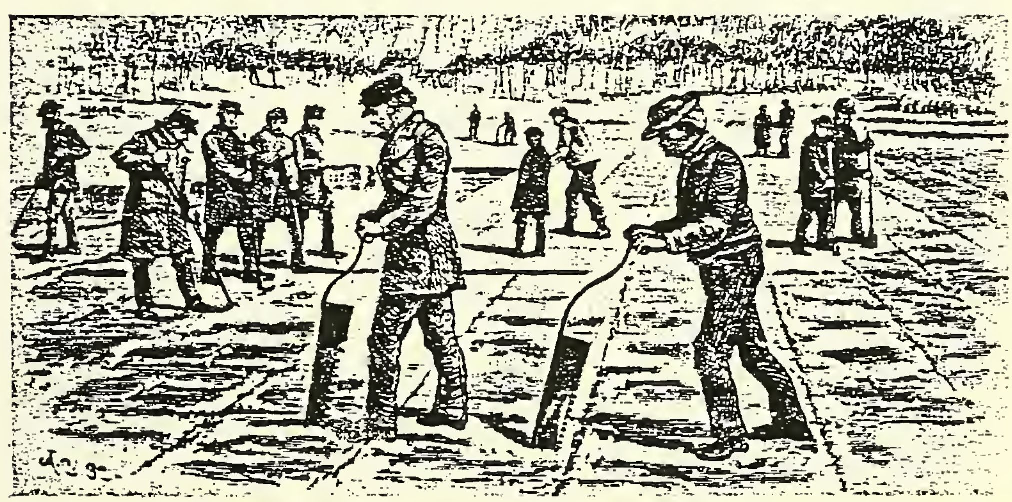
In harvesting natural ice, the first thing to be done was to scrape away the snow that had accumulated on the frozen surface.



Scribner's Monthly Magazine, 1875

GROOVING, FRESH POND, CAMBRIDGE

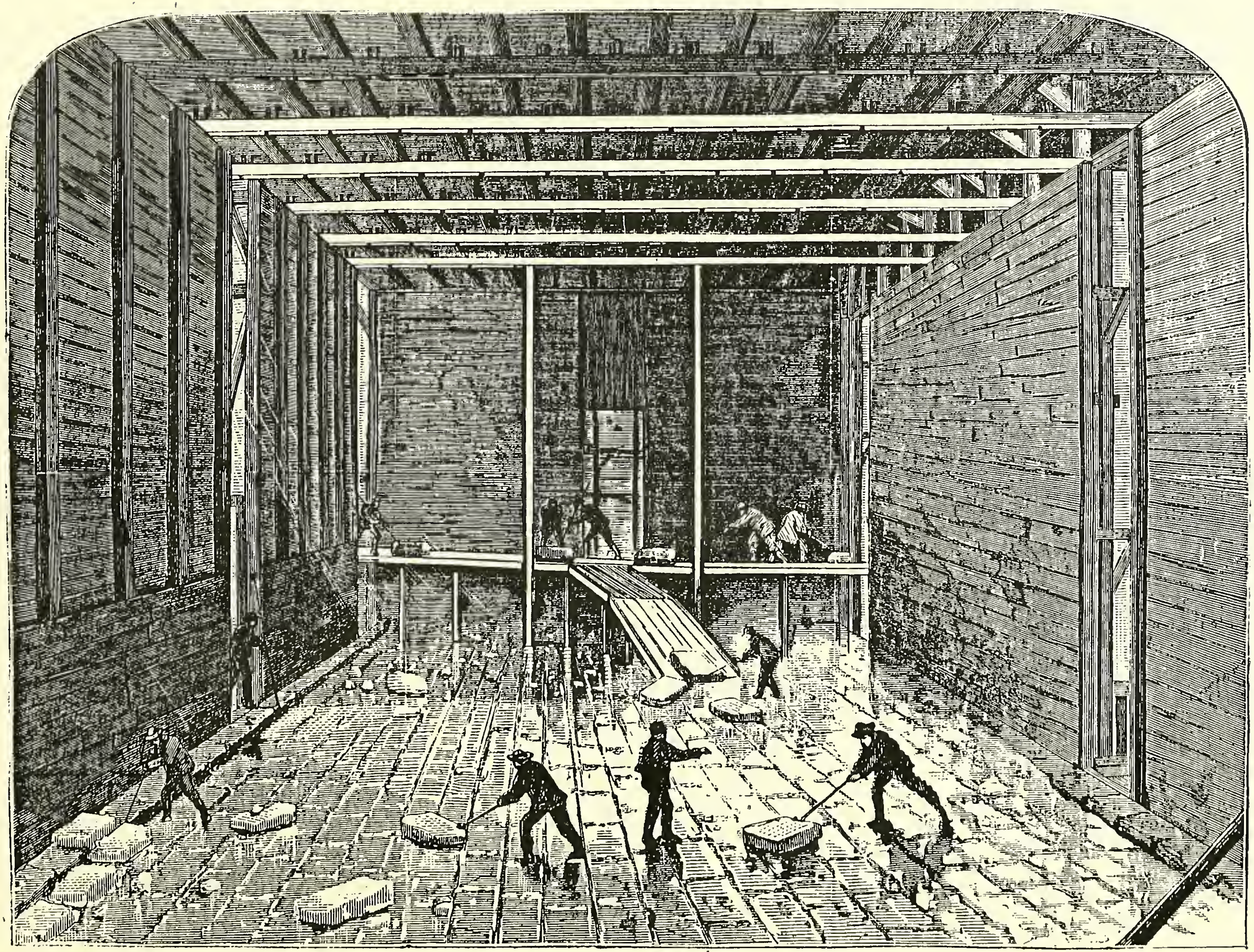
Various devices were used for "lining" the ice, checkerboard-fashion. The cutter shown here has blades to mark the surface next to be scored.



Scribner's Monthly Magazine, 1875

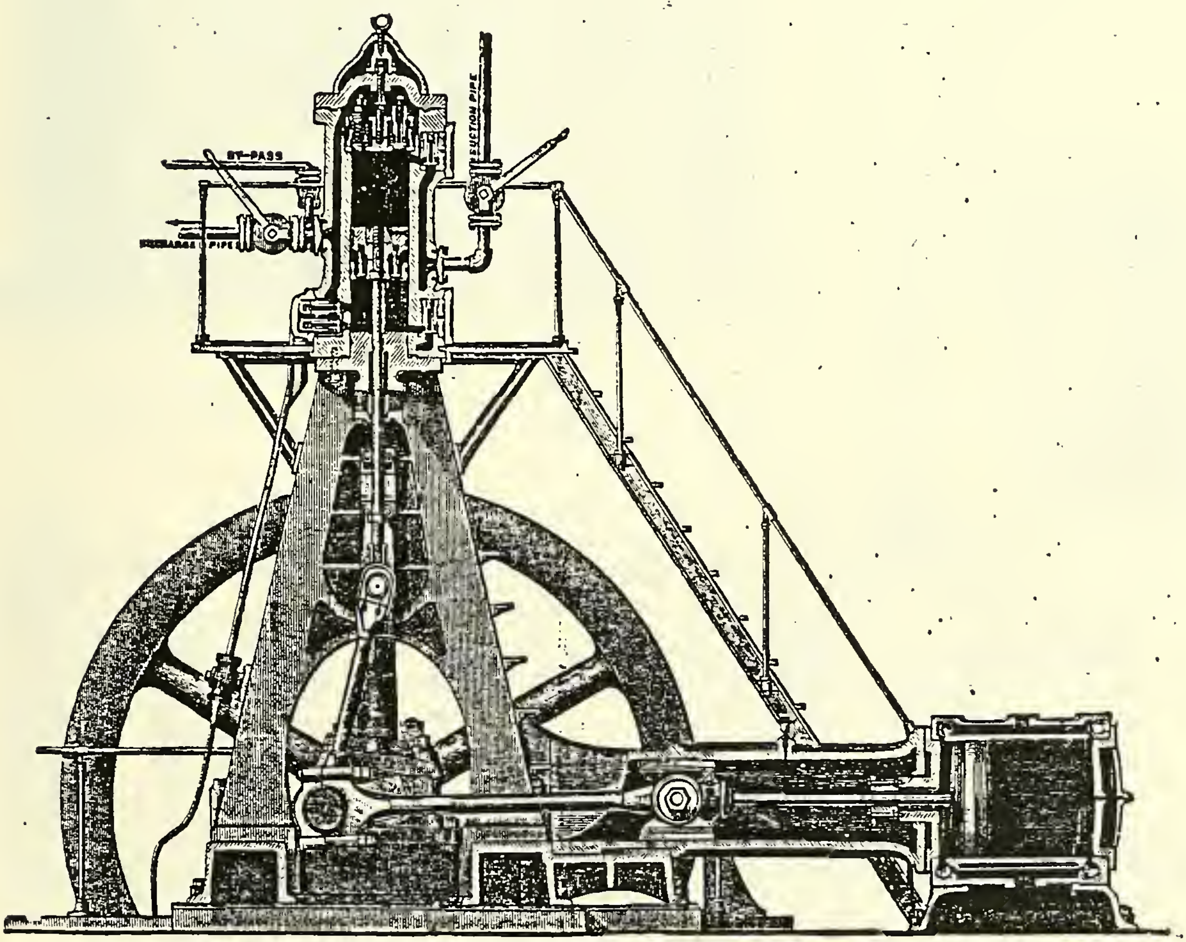
SAWING AND BREAKING OFF, FRESH POND

Long sections of ice have been scored and are being cut through, broken off, and floated into the channel of clear water.

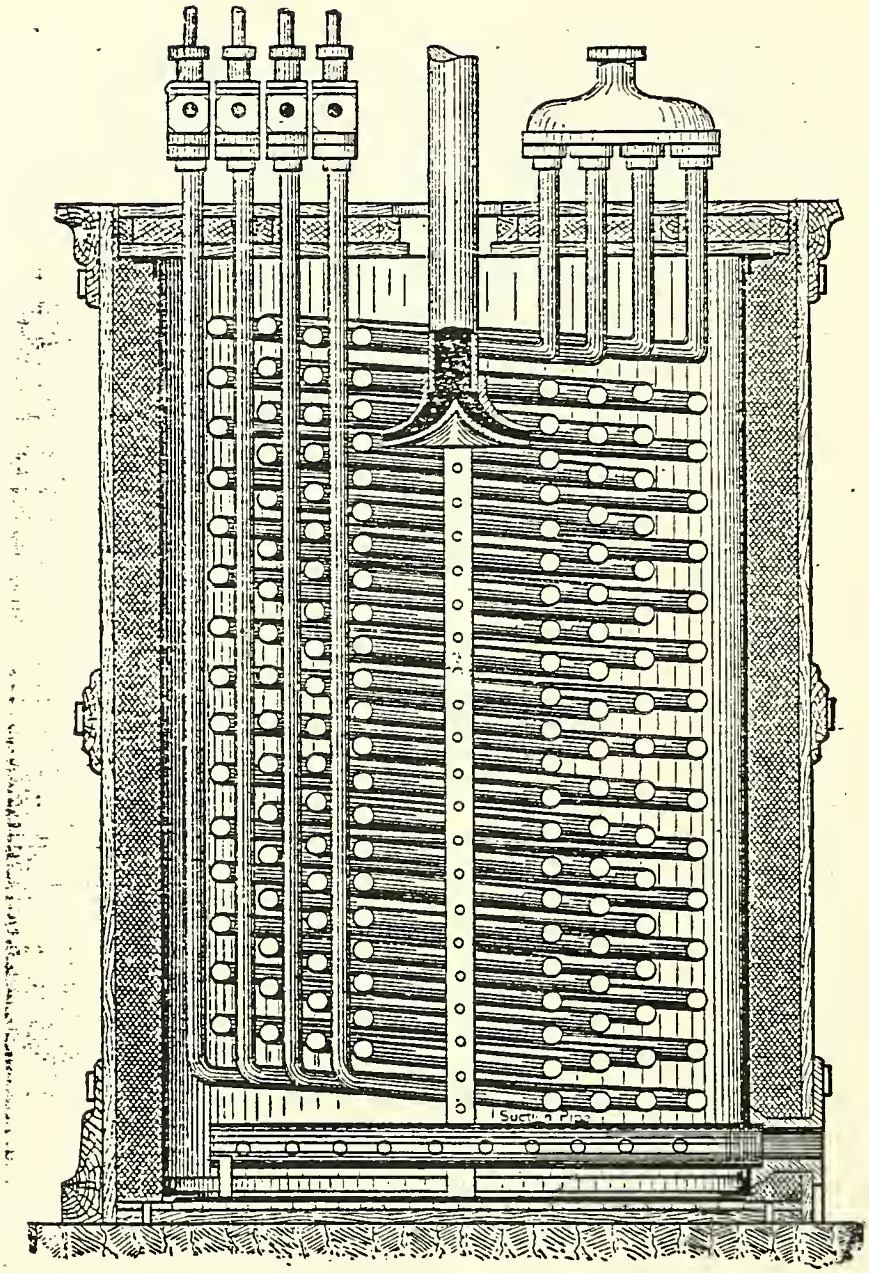


ICE HARVESTING ON THE HUDSON

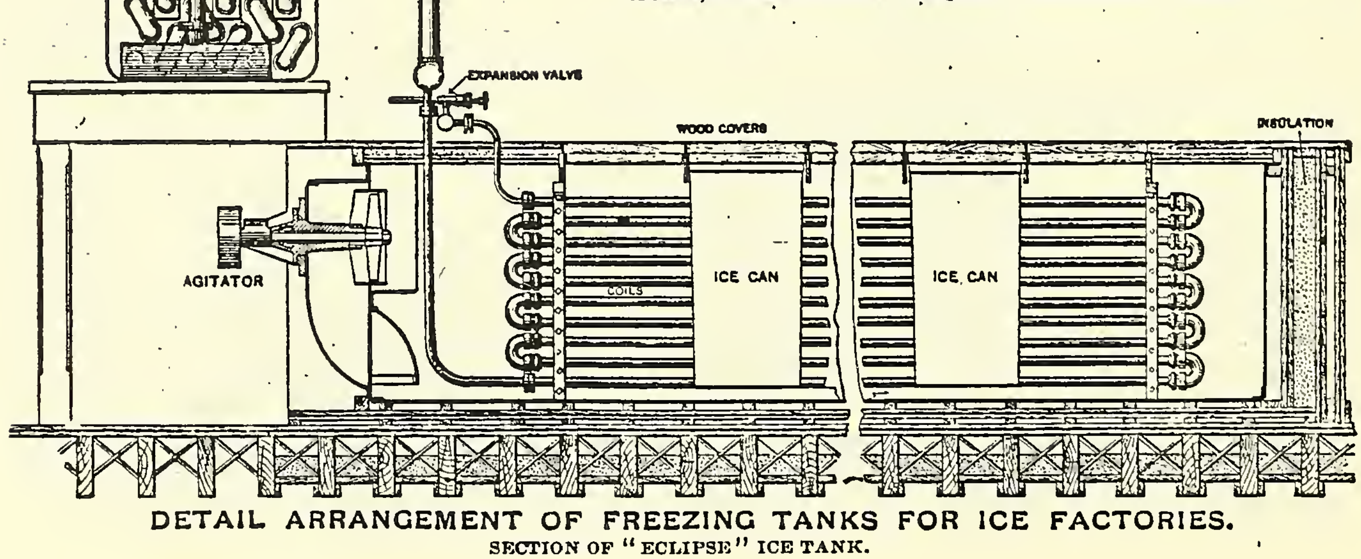
HISTORY OF REFRIGERATION



SECTIONAL VIEW OF VERTICAL REFRIGERATING MACHINE OPERATING WITH OIL INJECTION.



BRINE TANK.
Showing likewise the General Arrangement of the Submerged Condenser.



DETAIL ARRANGEMENT OF FREEZING TANKS FOR ICE FACTORIES.
SECTION OF "ECLIPSE" ICE TANK.

Faraday-
condensed ammonia to liquid; applied pressure and then cooled it.

Cullen - First ice machine; vacuum principle via an air pump in a vessel of water

Vallence of France - Mechanical sulphuric acid absorption method

---

Perkins of U.S. -
Forerunner of modern compression apparatus; model patented in England in 1834; employed ether as refrigerant.

Alexander Twining -

Produced 1st commercial ice by means of a vapor-compression machine; used ether, carbon disulphide or sulphur dioxide.

His first patent taken out in 1850.

James Harrison -
Immigranted to Australia from Scottland in 1837. Developed first vapor-compression machines for brewing, industry and meat freezing. Used ethyl ether as refrigerant.

Carre Brothers of France -
Absorption system - refrigerant absorbed in liquid; solution heated; drives off refrigerant as vapor, which is then condensed.

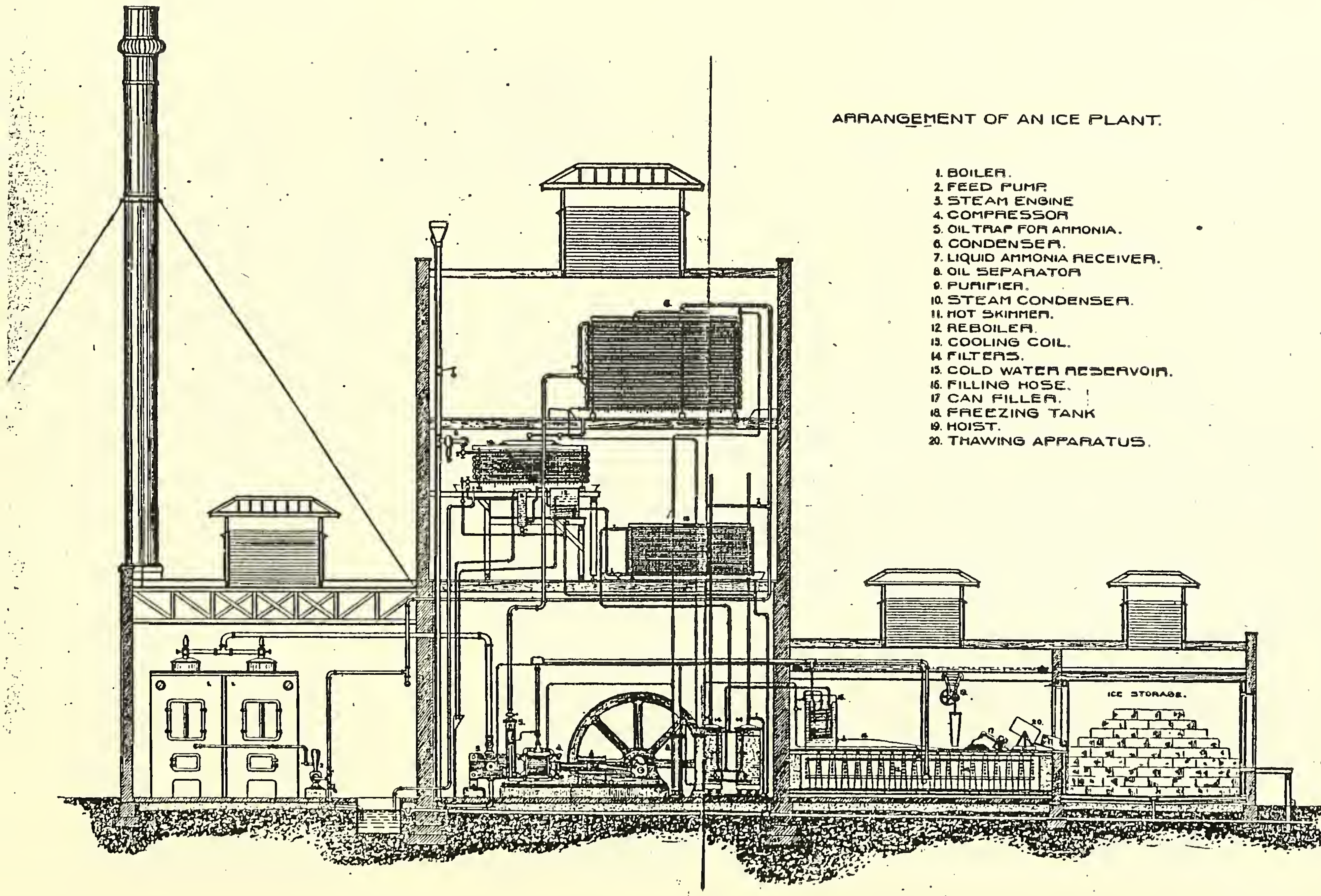
Edmund Carre -

Evaporated water vapor at very low pressures.

Ferdinand Carre -

Evaporated liquid anhydrous ammonia.

1865	-	1st artificial ice plant, New Orleans
		1st Refrigerator car
1870	-	Four ice making plants in United States
1871	-	Waco of Texas - cooled buildings via refrigeration coils in room ceilings
1872	-	Boyle, United States - invented successful ammonia compression machines
1873	-	Linde, Germany - successful ammonia compression machines
1874	-	Lyman, New York City - cooled rooms via blowing air over ice at ceiling
1876	-	Rankin - Absorption type refrigeration used in breweries
1879	-	DeLa Vergne - Ammonia compression machine with improved sealing and oil pumping
1888	-	Carbondale Machine Company - Installed its first industrial cooling process
1890	-	Natural ice shortage spared development and utilization of mechanical refrigeration
1903	-	Westinghouse Co. - Centrifigal compression refrigerating machines using water vapor
1904	-	York Corp. - System to freeze moisture out of blast air for Carnegie Steel
1910	-	Kelvinator - Sold first domestic refrigerator
1925	-	Willis Carrier - Invented centrifigal refrigerator machines
1938	-	Trane Company - Refrigerators with freon
1939	-	York Company - Centrifigal refrigerators



ARRANGEMENT OF AN ICE PLANT.

1. BOILER.
2. FEED PUMP.
3. STEAM ENGINE
4. COMPRESSOR
5. OIL TRAP FOR AMMONIA.
6. CONDENSER.
7. LIQUID AMMONIA RECEIVER.
8. OIL SEPARATOR
9. PURIFIER.
10. STEAM CONDENSER.
11. HOT SKIMMER.
12. REBOILER.
13. COOLING COIL.
14. FILTERS.
15. COLD WATER RESERVOIR.
16. FILLING HOSE.
17. CAN FILLER.
18. FREEZING TANK
19. HOIST.
20. THAWING APPARATUS.

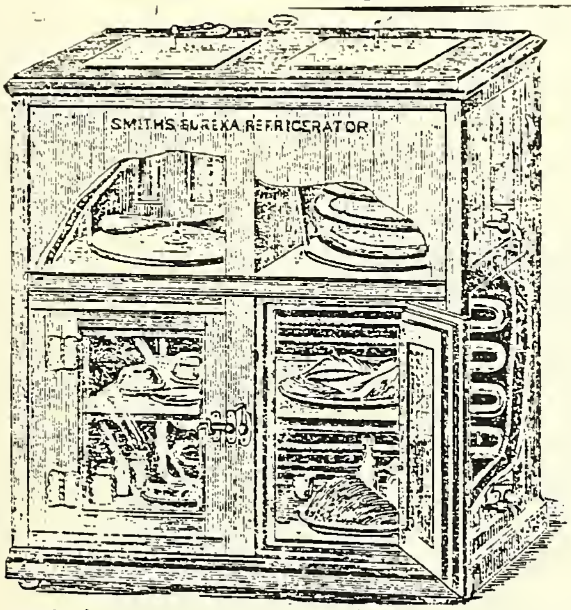
(To face p. 201)

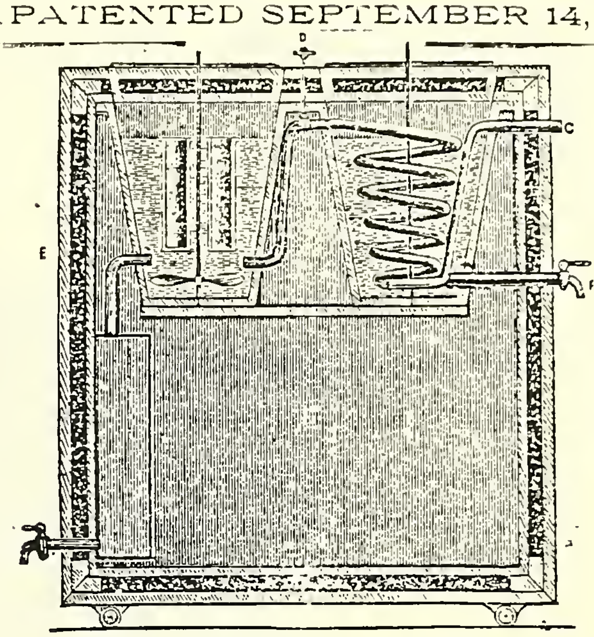
The Eureka Ice Machine

AND

Refrigerator.

PATENTED SEPTEMBER 14, 1886.





Of Interest to All who Use Ice. The Automatic Refrigerator.

Cold without Ice and Ice without Machinery.

When the brine has done most of its work and becomes somewhat warm in taking the heat out of the lower storage chamber, it is drawn off into a bucket once a day. Placed in a receptacle on the back of the stove and left to itself, the water will evaporate and the salt, when cool, is ready to use again; or place it in a shallow box or pan in the open air, you will accomplish the same results, at no cost.

There is an overflow pipe, at water line, from first to second tub. When the second tub is full, it overflows back to first, doing the initial cooling in the first tub, and an overflow pipe from first tub out to the drip pan, so that there is no chance for an overflow inside the refrigerator, or a mistake to be made.

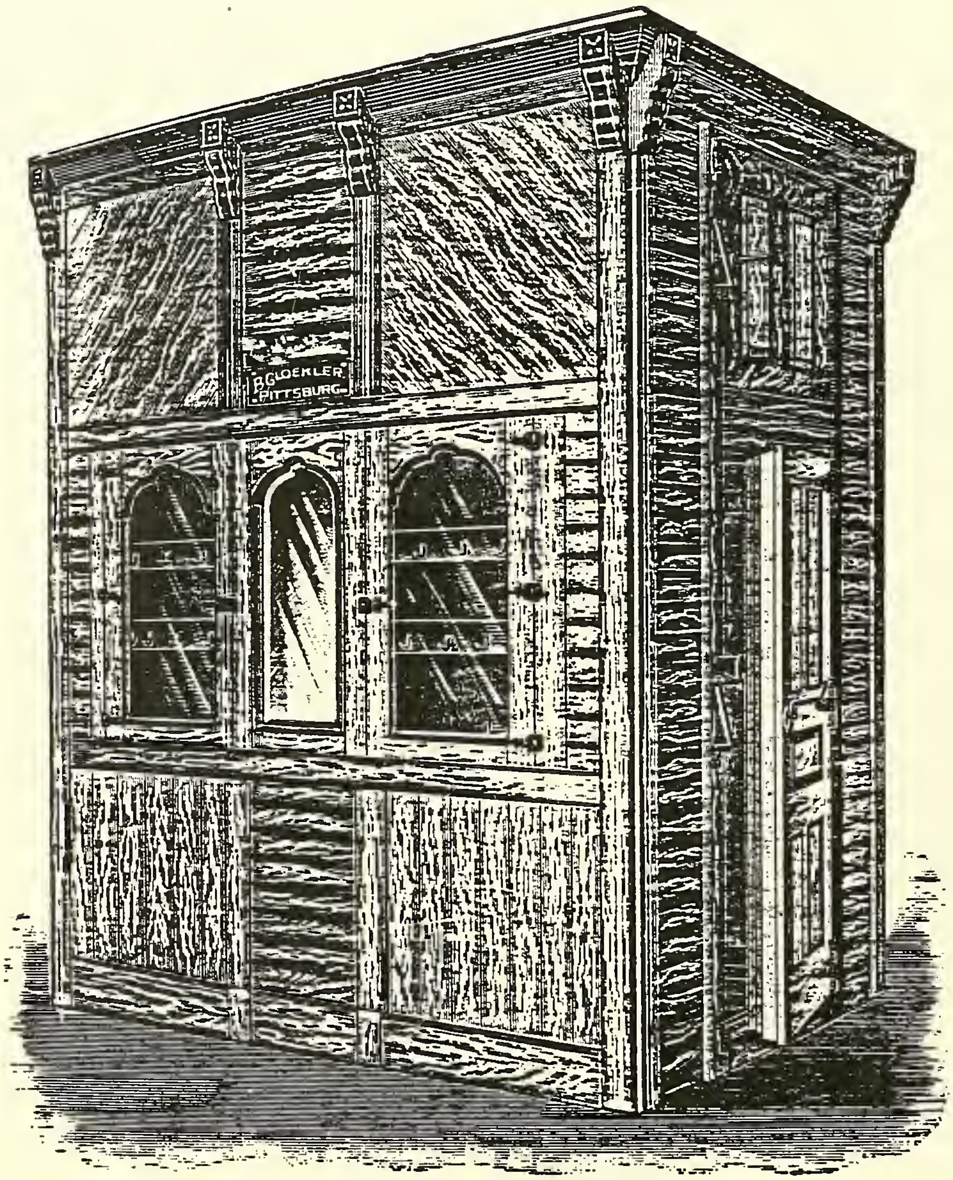
Small stirrers are seen in each tub, whose office is to stir the salt and water together, to hasten the dissolution of the salt and its mingling with the water. A few minutes each day, after adding the salt, is alone necessary for this purpose.

The chemical agent used in this process is nitrate of ammonia, a salt which possesses the wonderful property of absorbing heat the moment it dissolves in water. It is not decomposed at all, but simply passes into solution with the water, as sugar or ordinary salt. Hence, by simple evaporation of the exhausted brine when it has done its work in the refrigerator, the salt is recovered in the form of crystals and is again available for use. In other words, this agent loses none of its powers each time it is used, but may be employed indefinitely and without loss. In this way your ice bills are shut off for life, and your daily costs for refrigeration reduced to the evaporation of a little water. This chemical salt is readily obtainable, is pure, harmless and moreover a purifying agent.

Fresh water from some outside source, either a hydrant, or a barrel elevated above the machine, is connected to the coil of pipe in the right-hand tub, marked A. The object of this is to force fresh water through the coil chilled by the brine surrounding it. The water the coil contains is chilled, and a constant supply is always available for drinking or other purposes.

The letter C indicates the entrance of the fresh water to the coil and the letter F the tap by which the cool fresh water is drawn off for domestic purposes. The letter D indicates the valve by which some of the chilled water is allowed to drop into the left-hand tub marked B.

This cold water dropping into the tub, dissolves the chemical agent we use, and this dissolution produces an intense cold brine, such as the expensive power machinery machines produce after hours of work.

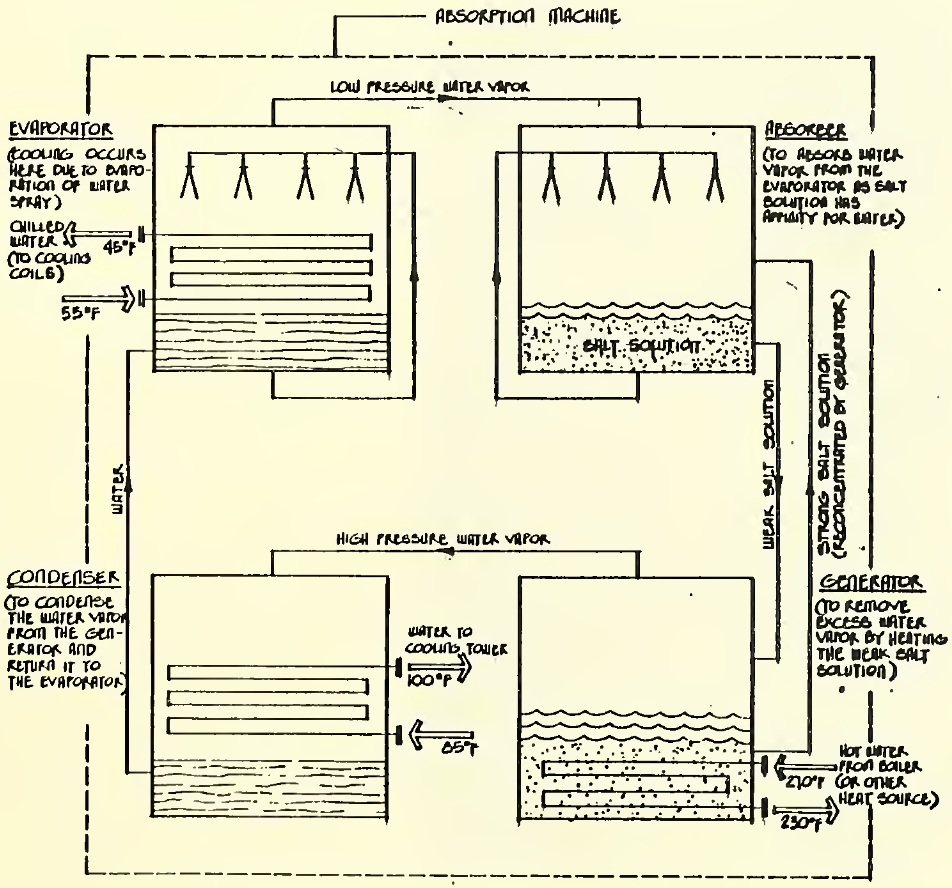


Walk-in freezer. *MacArthur*

AIR CONDITIONING & REFRIGERATION

MECHANICAL SYSTEMS—COOLING: ABSORPTION REFRIGERATION CYCLE

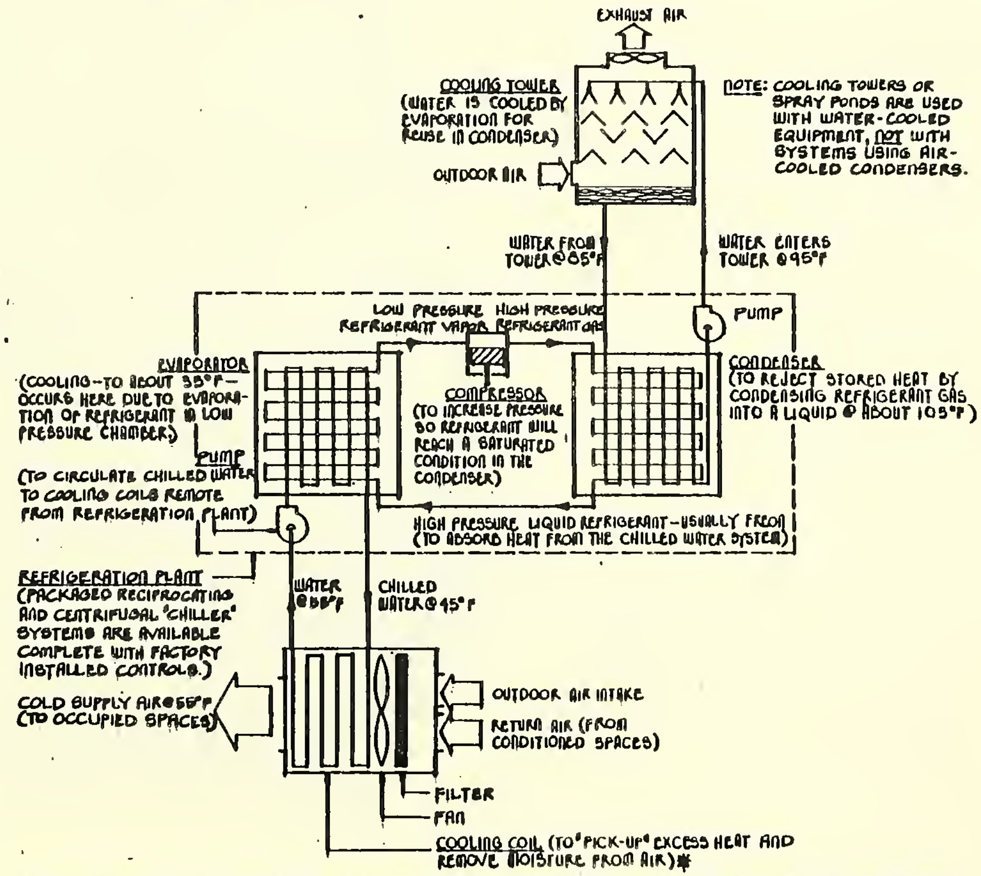
Cooling by absorption is shown by the diagram below. Chilled water is produced by using an absorbent salt solution (usually lithium bromide) and by controlling its properties with hot water and cooling tower water. An inexpensive source of hot water or steam is required to make the absorption cycle economically competitive with the compressive cycle (See page 97).



Note: The only moving parts in an absorption refrigeration machine are the circulating pumps. Nevertheless, it should be supported by resilient isolators (See Section 6).

MECHANICAL SYSTEMS—COOLING: COMPRESSIVE REFRIGERATION CYCLE

The process of removing heat from interior spaces to the outdoors is based on the principle of thermodynamics that heat will move to a cooler medium. Cooling by mechanical compression is shown by the diagram below. Heat is transferred from the chilled water system (See evaporator-cooling coil cycle) to the condenser water system (See condenser-cooling tower cycle) by means of changing the state of a refrigerant (See Freon compressor cycle) which gives off and absorbs heat.



* THIS PROCESS IS SIMILAR TO WHAT NORMALLY OCCURS IN NATURE. FOR EXAMPLE, WHEN A WARM-AIR MASS MEETS A COLD FRONT THE AIR IS COOLED AND LOSES ITS CAPACITY TO HOLD MOISTURE. AS A CONSEQUENCE, THE MOISTURE CONDENSES AND FALLS AS RAIN.

REFRIGERATION SYSTEMS

SPACE COOLING TECHNOLOGY

Although in very specialized instances such as theaters and mansions, ice was used to space cool in olden times; and in dry climates, effective cooling could be achieved via a simple evaporation system; it was not until the perfection of mechanical cooling and the ability to deal with humidity was large scale space cooling in use. As power was quite plentiful and cheap, very sophisticated but energy intensive systems were developed to cool large commercial and institutional buildings in the hot seasons. The more prevelant systems are:

1. Reciprocating (piston) compressor - most jobs under 60 ton and some from 60T - 200T.

2. Centrificial Compressor - large capacity and higher temperature lift.

3. Absorption - water as refrigerant; salt solution as absorbent. Quiet system for larger jobs. Good when electricity is expensive and steam cheap.

4. Absorption centrifigal combination -- 1/3 centrifical and 2/3 absorption saves steam on larger jobs.

5. Thermocouple (Peltier) -- special uses, space vehicles.

6. Steam Jet Refrigeration - water is refrigerant; steamjet compresses water vapor; condensors - both water and steam.

BISMUTH TELLURIDE THERMOCOUPLE

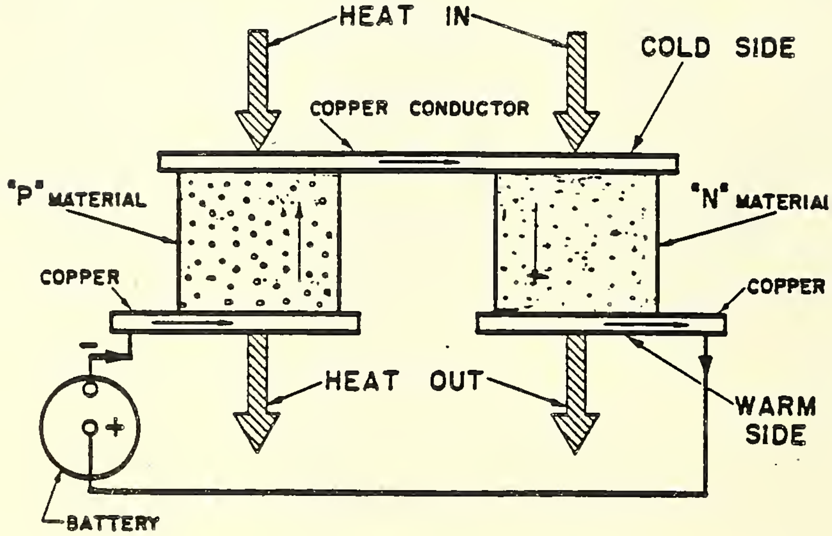


FIG. 1 THE BASIC THERMOCOUPLE

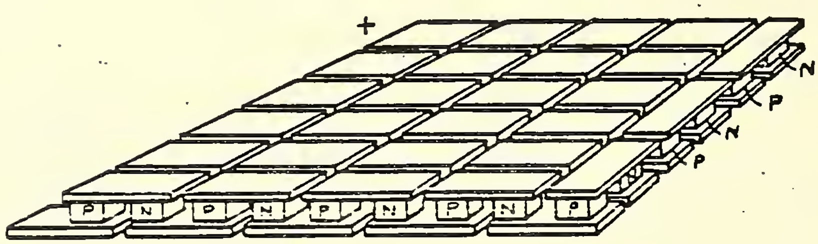
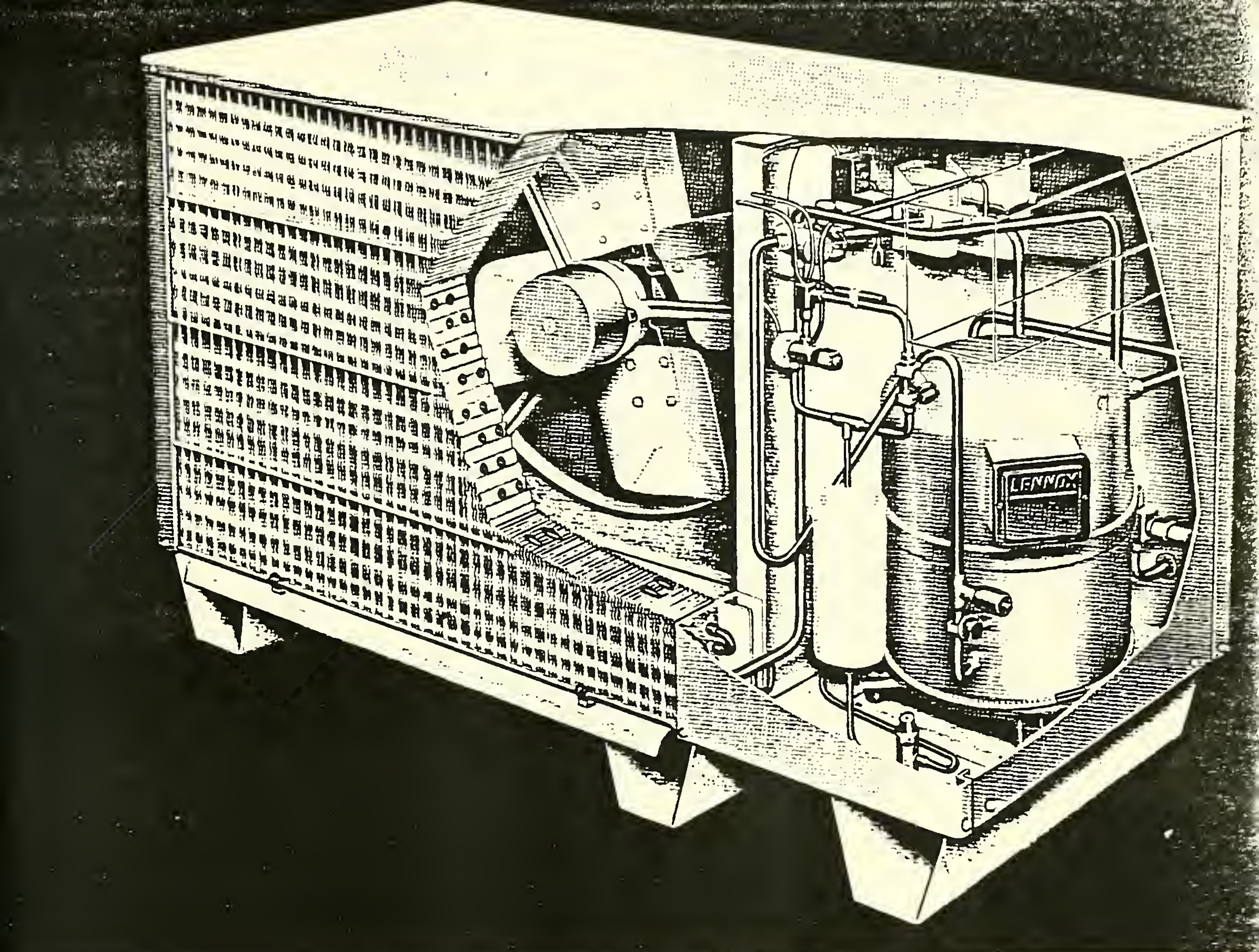


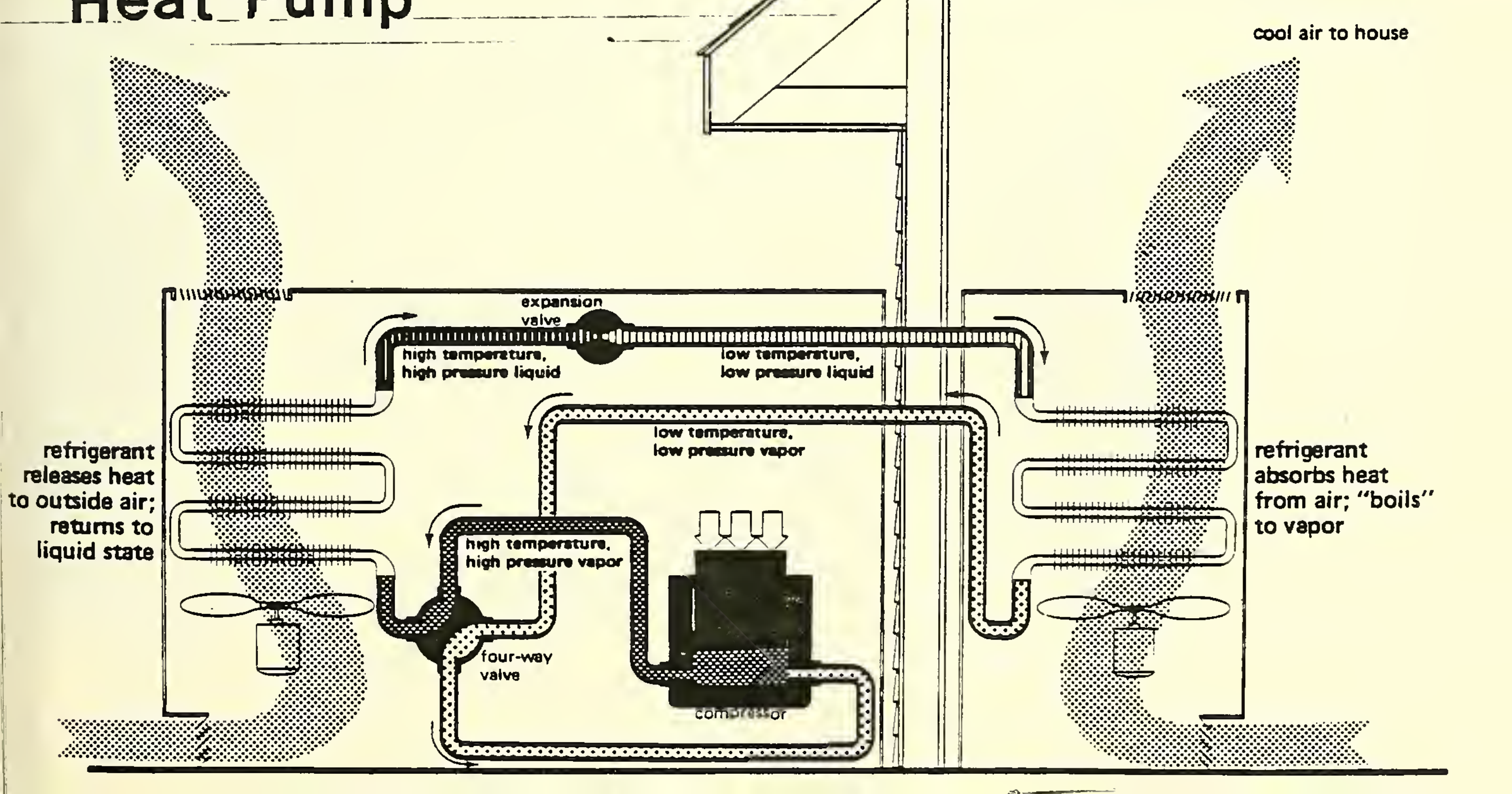
FIG. 2 CONVENTIONAL MULTI COUPLE MODULE

Usually the billets of bismuth telluride P and N materials are soldered directly to electrical buss connections, as shown in Fig. 1. These couples are quite generally formed into modules which provide for a series electrical path thru the couples and for parallel pumping of heat. Such a module is shown in Fig. 2. Its use is illustrated in Fig. 3, wherein the modules occupy the center portion of a thermoelectric ice making assembly. The electrically conducting surfaces of the module must be in relatively close contact with the cooling plate on which the water is to be frozen, as well as in similar proximity to the sink surfaces which remove the heat pumped by the couples. At the same time good electrical insulation is required to prevent short circuiting of the couples by these adjacent heat transfer components. This is frequently accomplished by the combined use of aluminum oxide or other ceramic chips, and suitable soldering techniques or application of thermally conducting mastics.



Cooling Cycle

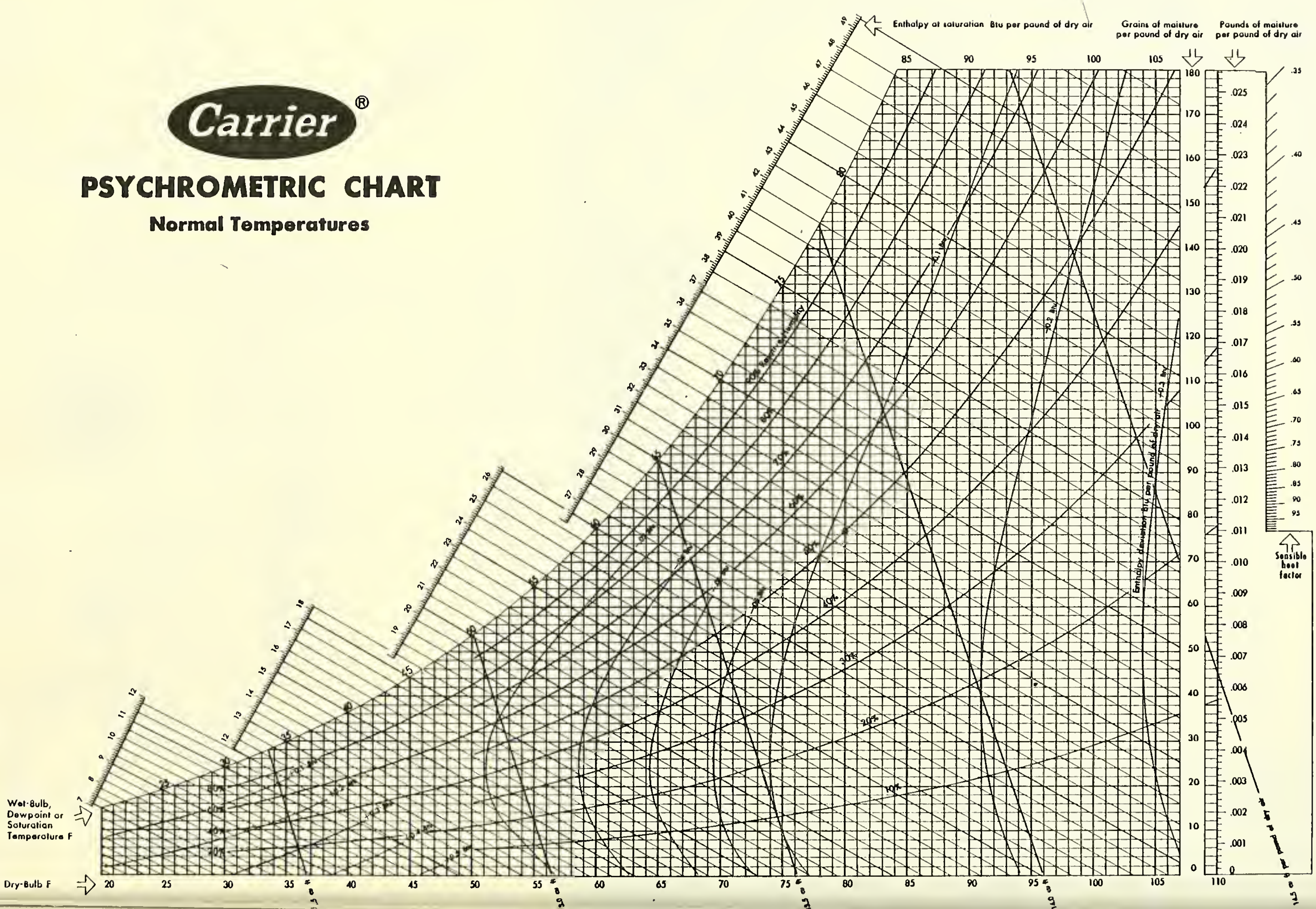
Heat Pump



Carrier®

PSYCHROMETRIC CHART

Normal Temperatures



Absorption Cooling -

Water used as refrigerant; its vapor absorbed by a salt solution.

Dew Point -

The temperature at which the moisture in air condenses.

Enthalpy -

The total heat in air over $0^{o}F$ including the latent heat of water vapor.

Foam Insulation -

Plastic foams widely used for insulation such as polyurethane and polystyrene, available in slab, laminated to other materials, or sprayed right on objects.

Heat Pumps -

Equipment which produces either hot or cold in its compressor and evaporator elements.

Mechanical (Vapor Compression Cooling) -

Achieves cooling by evaporation of a compressed liquid refrigerant to a gas.

Pneumatic Conveying System -

Conveys and discharges flaked ice.

Rake, Ice -

Automatically stores and discharges ice.

THREE COMPONENTS OF REFRIGERATION

1. <u>Compressor</u>

Can be open or hermetic (sealed) and can be driven by a motor, engine, or turbine to produce a high temperature, high pressure vapor.

2. <u>Condensor</u>

Rejects heat from this vapor via water, air, or evaporation with sprayed coils. A cooling tower is often used in conjunction with the watercooled condensor.

3. <u>Evaporator</u>

The condensed gas reverts back to a vapor and in so doing absorbs heat from cooling medium.

In space cooling, not only the sensible heat of the air must be removed but also the latent heat of the water vapor (humidity) which averages 1,061 BTU per lb. of moisture.

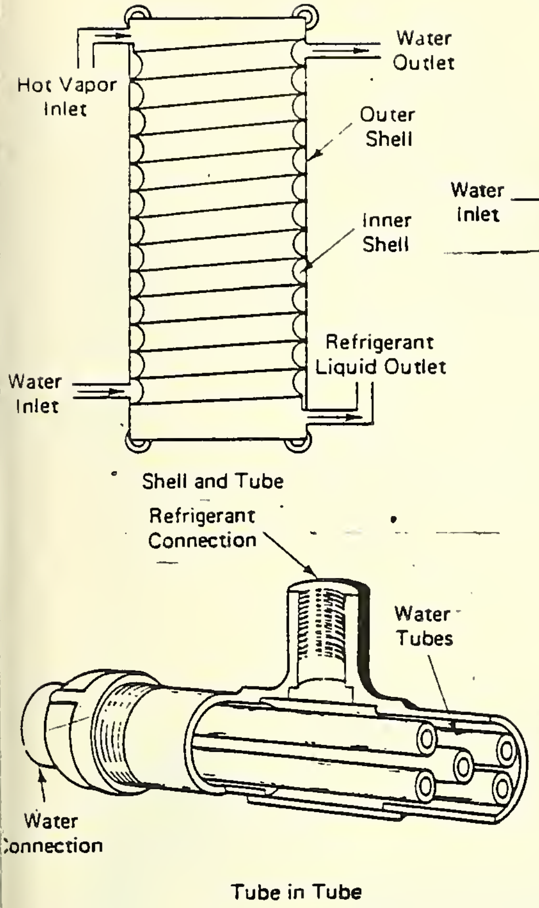


Figure 5-10. Water-cooled condensers

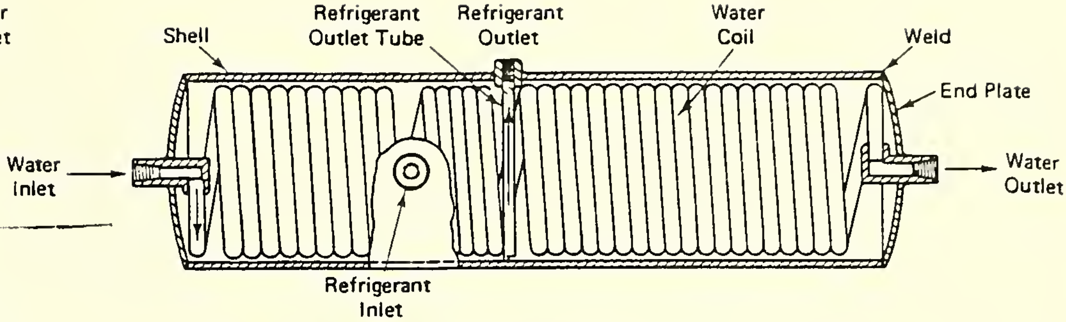


Figure 5-11. Shell and tube condenser

Condenser

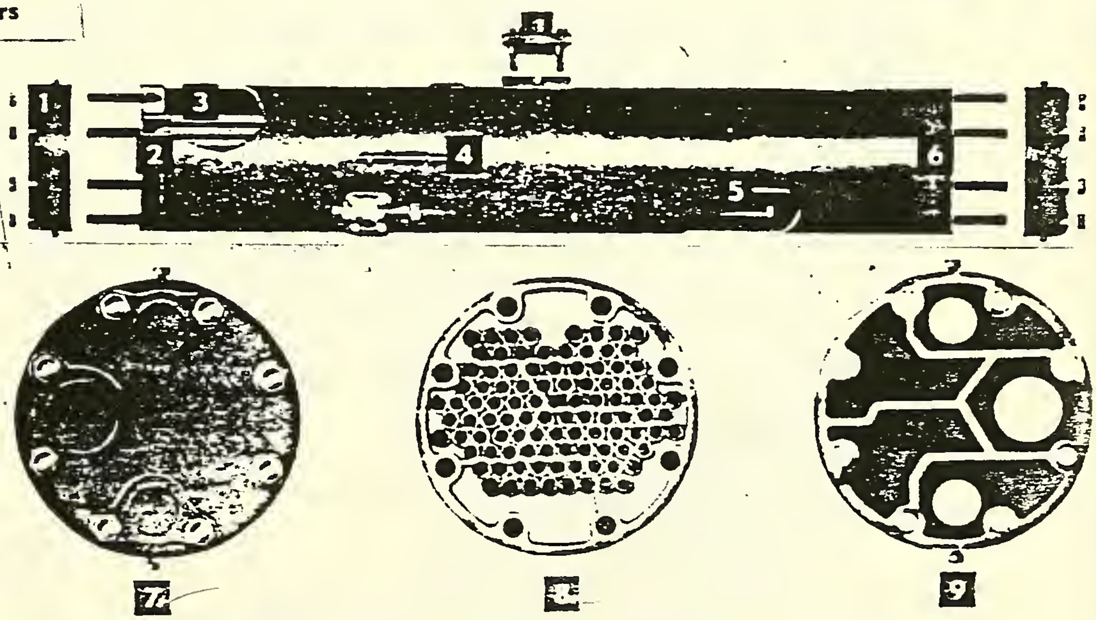


Figure 5-12. Multipass water-cooled condenser with bolted-in-place ends

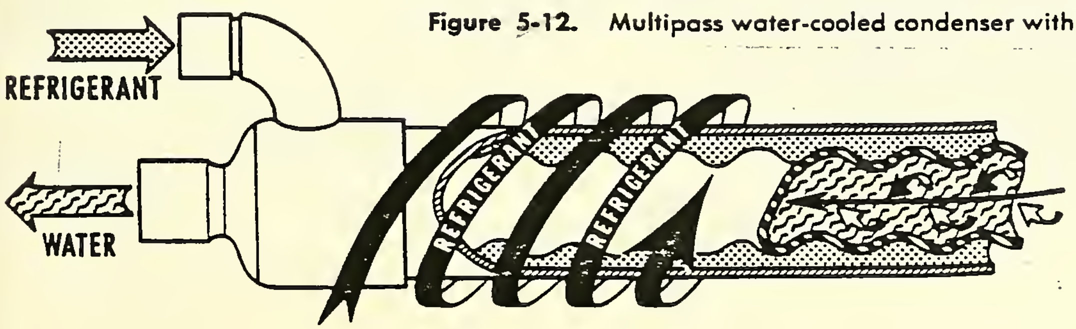


Figure 5-18. Counterswirl design principle (Courtesy of *Packless Industries*)

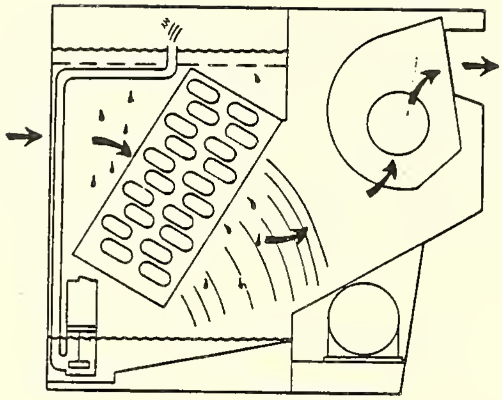


Fig. 44 – Evaporative Condenser

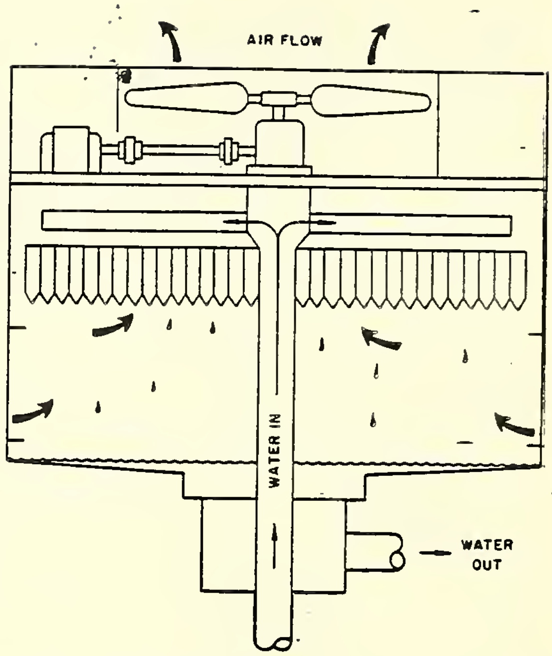


Fig. 46 – Cooling Tower

Cooling Tower

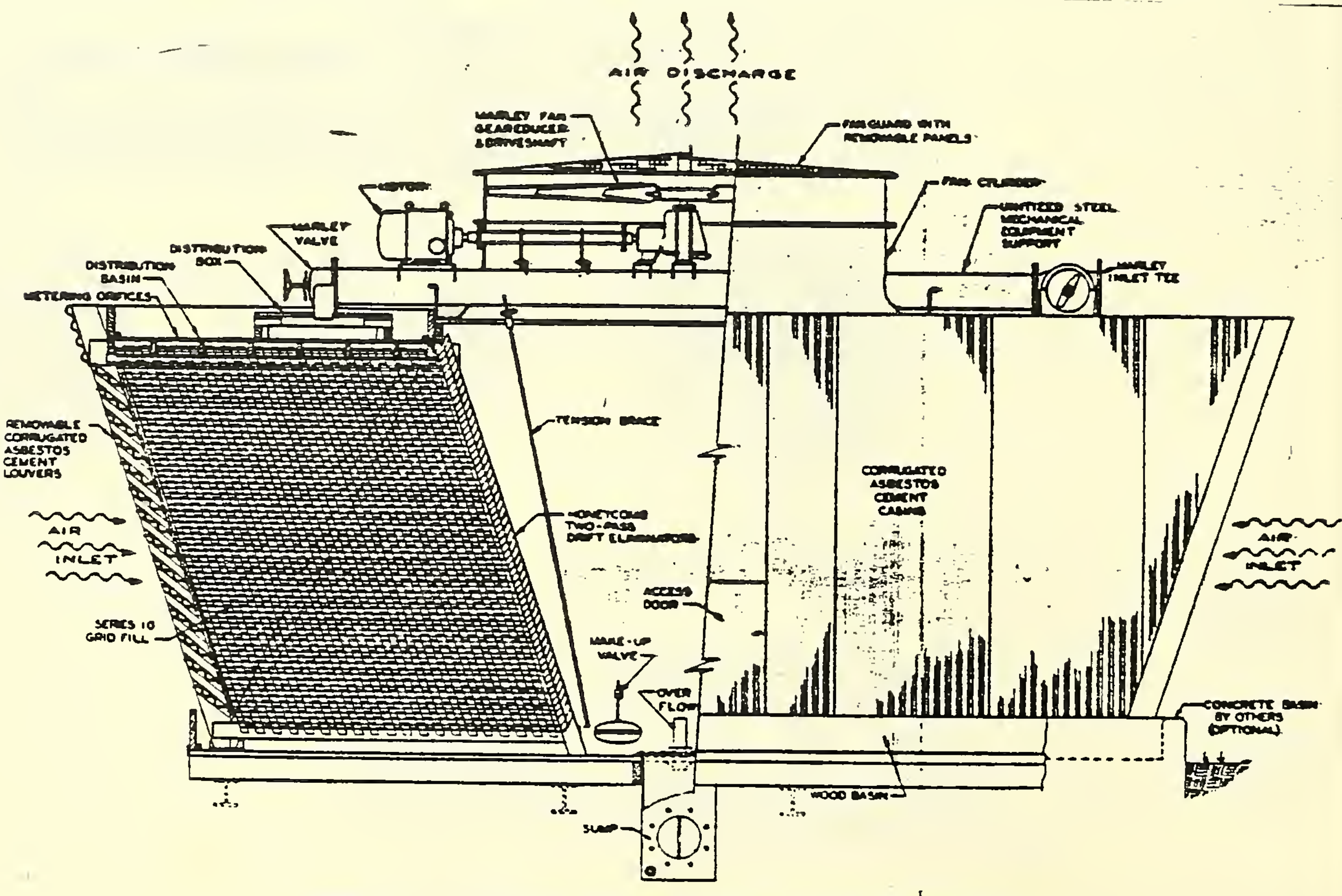
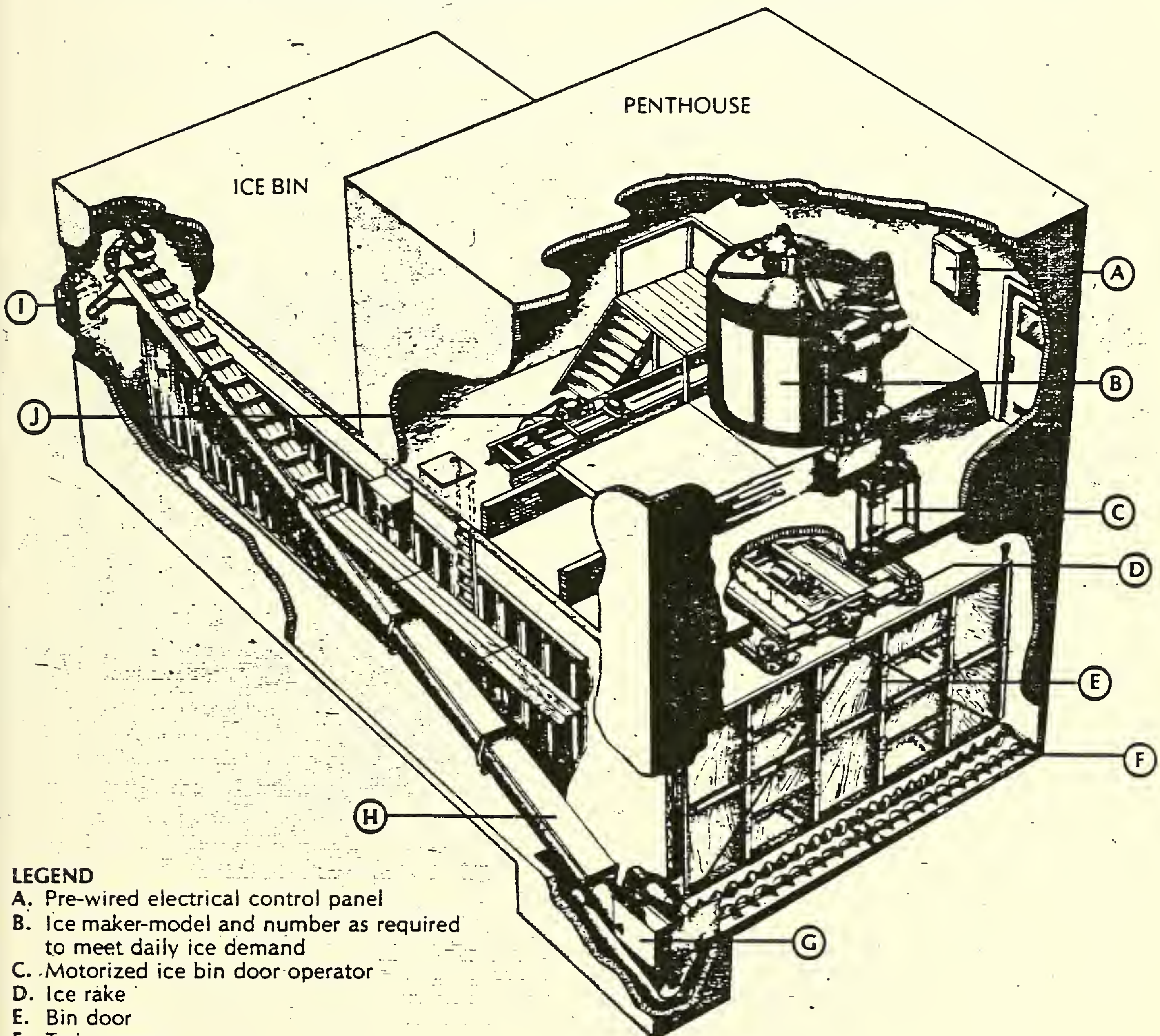


FIG. 6–14 Cooling Tower (Courtesy: The Marley Co.)

ICE PLANTS

TYPICAL SINGLE RECTANGULAR ICE STORAGE AND HANDLING SYSTEM

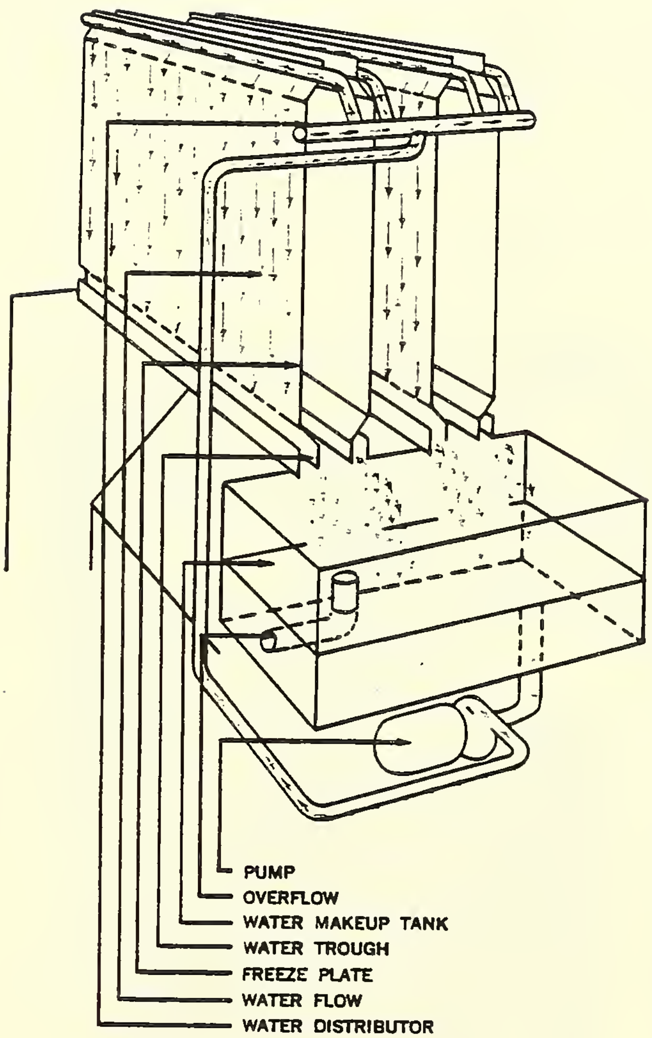


LEGEND

A. Pre-wired electrical control panel
B. Ice maker-model and number as required to meet daily ice demand
C. Motorized ice bin door operator
D. Ice rake
E. Bin door
F. Twin screws
G. Feed reservoir
H. Elevating screw conveyor
I. Motorized ice discharge door-screw conveyors beyond as required
J. Ice rake hoist

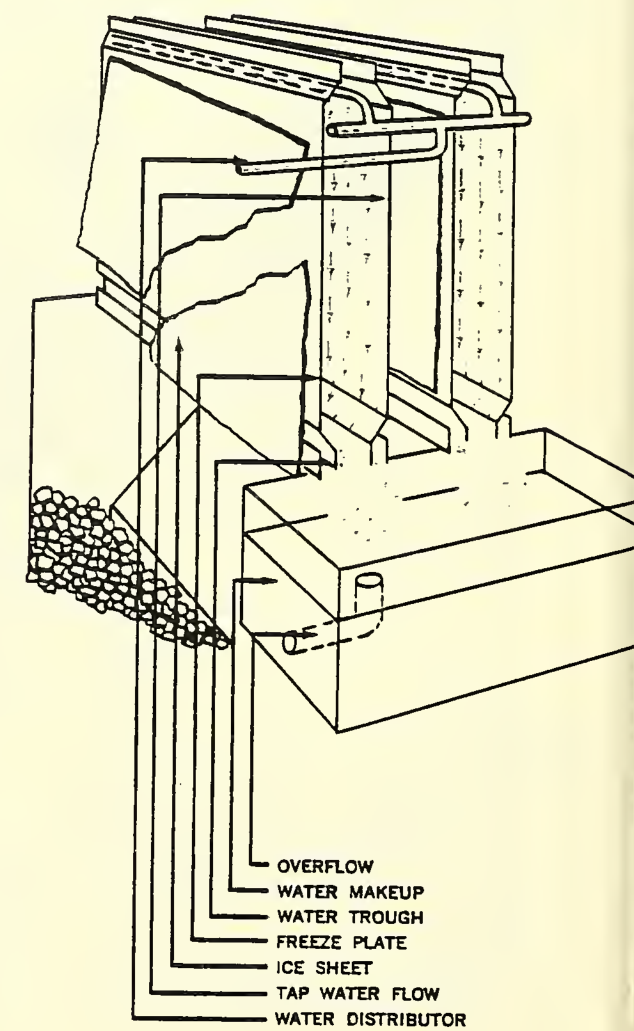
PLATE ICE MAKER

ICE FREEZING CYCLE



Water is sprayed on freezing plates and flows by gravity over plates in freezing cycle.

ICE HARVESTING CYCLE



For harvesting, fresh water is sprayed on back of plates, releasing ice which falls by gravity into a breaker bin where the ice is broken into pieces of the selected size. Exclusive ice drying cycle is built in.

RECENT INNOVATIONS IN ENERGY SAVING TECHNOLOGIES IN MECHANICAL COOLING SYSTEMS

Variable Volumn - controls match blower speed and air volumn to demand

Connections - between hot and cold zones

Heat Wheels - motor driven wheel of heat absorbant material to transfer heat from exhaust air to fresh air intake

Heat Recovery - for heating and hot water

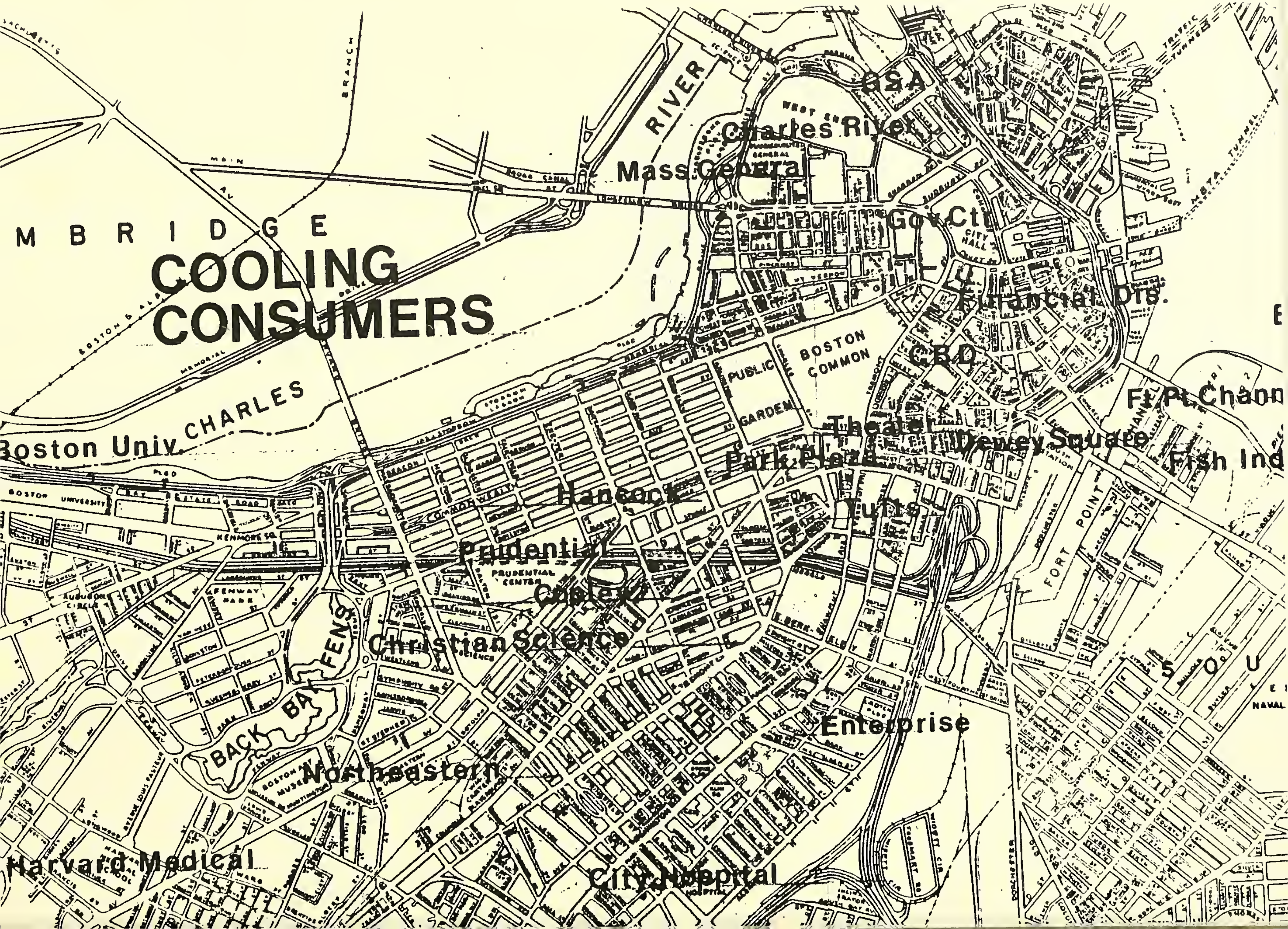
supermarket - freezer to customer area
restaurant - refrigerator to hot water

Strainer Cycle - during milder seasons (Spring and Fall)

compressor and condensor turned off
building cooled by cooling tower
"strainer" - strains dirt from cooling tower return water

Removing Heat - from lights in exhaust

CURRENT CONSUMERS AND DEMAND LOADS


COOLING
CONSUMERS
GSA
Charles River
Mass General
Gov Ctr
Financial Dis.
CBD
Ft Pt Chann
Theater
Dewey Square
Fish Ind
Park Plaza
Hancock
Tufts
Prudential
Copley
Christian Science
Enterprise
Northeastern
Harvard Medical
City Hospital
Boston Univ
BOSTON COMMON
PUBLIC GARDEN
RIVER
CHARLES
FENS
BACK BAY
FORT POINT
M B R I D G E
S O U

HOW BUILDINGS ARE HEATED

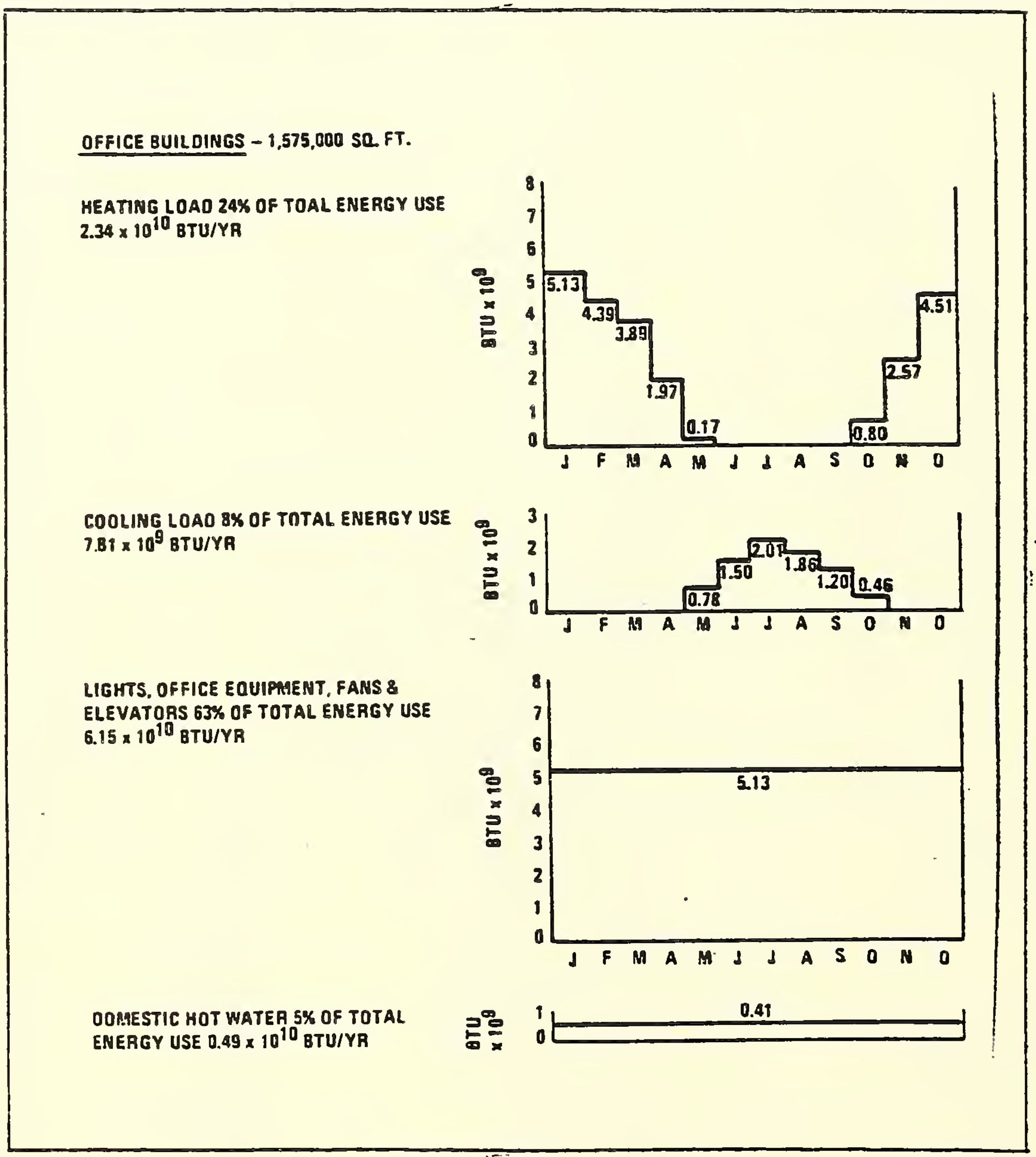
	Oil	Edison Steam	Gas	Electric
Financial	36.8%	52.6%	5.3%	5.3%
Back Bay	54.5%	39.4%	6.1%	-
Midtown	44.4%	55.6%	-	-
Government	37.5%	50.0%	6.3%	6.3%
Class A	11.8%	76.5%	5.9%	5.9%
Class B	45.0%	40.0%	15.0%	-
Class C	50.8%	45.9%	-	3.3%
Class D	50.0%	33.3%	16.7%	-
Total City	43.8%	48.6%	4.8%	2.9%

Response - 100%

BOSTON END USE ANALYSIS
(Percentages)

	Residential	Commercial	Industrial	Municipal
Space Heating	69.2	48.6	.8	62.0
Space Cooling	.4	11.8	.2	7.0
Water Heating	20.1	8.0	--	5.8
Cooking	4.0	--	--	--
Lighting	1.6	16.6	.7	14.0
Clothes Drying	.5	--	--	--
Refrigeration	2.5	1.1	--	--
Appliances	1.7	--	--	--
Direct Heating	--	--	18.9	--
Raw Materials	--	--	19.1	--
Process Steam	--	--	32.0	--
Electricity Generation	--	--	2.6	--
Coke Production	--	--	--	--
Machine Drive	--	--	7.3	--
Electrolytic Process	--	--	1.5	--
Other	--	13.9	16.9	11.2

Figure 5.4-1. North Station Project's Office Space: Estimated Annual Energy Profile by Month for Phases I and II



ARGONNE NATIONAL LABORATORY U of C-AUA-USDOE	SITE AND NEIGHBORHOOD DESIGN/DEVELOPMENT
	DEVELOPERS ENERGY EFFICIENT DEVELOPMENT PLANNING RFP 81-20-010
	CLIMATIC DESIGN/SUMMARY DATA SHEET

Complete the following Design Data Table:

97 1/2% T_{db}:	9 °F [a]	Wind Speed	12.6 [c]	Avg. Winter T	40 [b] °F
2 1/2% T_{db}:	88 °F [a]	T_{wb}	74 °F [a]	Daily Range	16 [a] °F

Complete the following Monthly Data Table:

Month	Heating Degree Days [c]	Cooling Degree Days [c]	Cooling Hours [d]	$\bar{T}_a$	$\bar{T}$ min [c]	$\bar{T}$ max [c]	% Sun. [c]	Average Wind Speed [c]
January	1110	0	0	29.2	22.5	35.9	53	14.3
February	969	0	0	30.4	23.3	37.5	57	14.1
March	834	0	0	38.1	31.5	44.6	57	13.9
April	492	0	0	48.6	40.8	56.3	57	13.3
May	218	20	21	58.6	50.1	67.1	59	12.2
June	27	117	122	68.6	59.3	76.6	64	11.4
July	0	260	271	73.3	65.1	81.4	66	10.9
August	8	203	212	71.3	63.3	79.3	66	10.7
September	76	61	64	64.5	56.7	72.2	64	11.3
October	301	0	0	55.4	47.5	63.2	61	12.1
November	594	0	0	45.2	38.7	51.7	51	12.9
December	992	0	0	33.0	26.6	39.3	53	13.7
Annual	5621	661	690	51.3	43.8	58.7	60	12.6

Sources for Data:

a. ASHRAE 77 Fund.

b. ASHRAE 77 Syst.

c. NOAA 1980 Annual Summ. Boston

d. Calculated at 1.04 h/DDC 65 °F base for 88 °F DB Design temp.

e.

USER	SYSTEM	TONS	# STEAM	KWH
M.G.H.	EDISON STEAM ELECTRIC		530 M LB STEAM	44 M KWH
CITY HOSP.	EDISON STEAM	415 MBTU [illegible]		
PRUDENTIAL				
JOHN HANCOCK TOWER...				
CITY HALL				
TUFTS	EDISON	[illegible] HOSP		
BOSTON UNIV.	OWN STEAM ABSORPTION	2100 - new 50-100 - each old		
MATEP	centrifugal chillers w/ motor & condensing steam drives	6 COOLING TOWER cells @ 11 kgpm 15K	1 M lb./hr.	52K K[illegible]
CHARLES RIVER	own steam absorption		4 Boilers @ 3K LB / HR	
CHRISTIAN SCIENCE	own steam	2240		
KENNEDY BLDG		63 M lb, steam / year		
GSA @ N. Station		"		
BOSTON FISH IND.	[illegible]	40K TONS ice / year		
COPLEY PLACE	ELECTRIC			56 M KW year
EXCHANGE PLACE	"			202 M K[illegible]
DEWEY SQ	"	3K TONS COOLING.	3 centrifugal Elec. machines	18.4 M K[illegible] year
1 POST OFF. SQ	"			17 M kw year
[illegible] Plaza Project	"			14 M KWH year
[illegible] Transportation Bldg	"			
60 State	"		29K / HR.	5600 KWH peak

DEMAND

Boston Edisons central steam system sends out 1.7 million lb./hr. steam over 22 miles of lines. Many of the older commercial and institutional complexes space condition with 90% of the 1.6 million lb. sent in winter @ $14/lb. and the 70K lb. in the summer @ $10/lb. The Kneeland Street station supplies the largest volumn of 1.1 million lbs./hr.; while the Minot and Scotia stations supply 230K lb. and 330K lb. respectively.

As the efficiency of absorption cooling, has gone down over the past several years, consumption has been dropping from the peak in 1976.

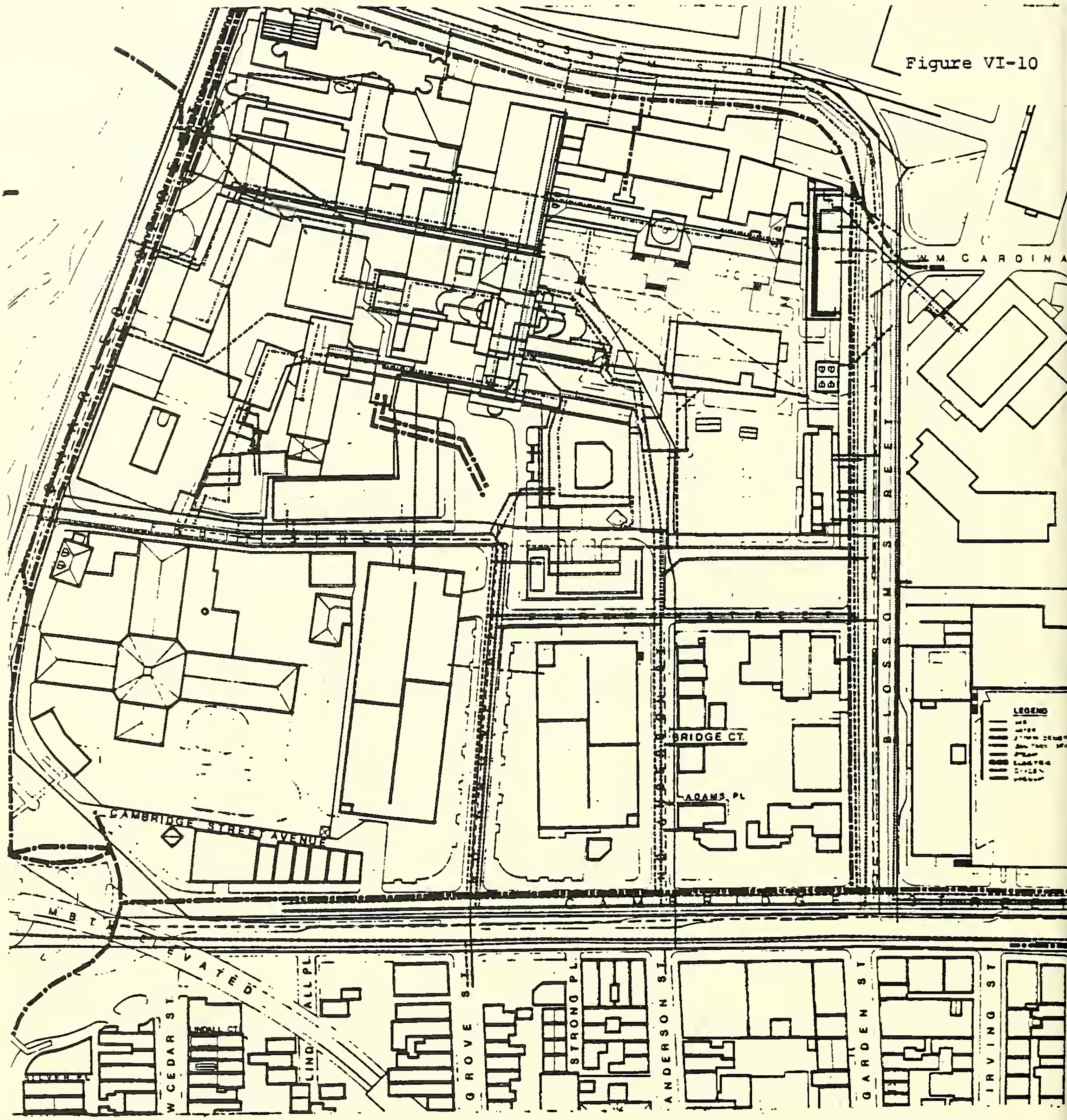
The process of absorption cooling with steam (Edisons or self generated) has become extremely inefficient and costly with the exception of the year's four hottest days. As a consequence, all new construction is installing totally electric power pay back in a couple of years. Some of the larger consumers of KWH are the Copley Place project at 56 million kwh/yr; Exchange Place at 20 million; and Dewey Square Tower and One Post Office Square at 18.5 million; and 17 million respectively.

As it is quite out dated, the L Street station has been closed down. Talks are now taking place with Wheelabrator Frye about the possibilities of constructing a solid waste facility in Boston similar to the plant in Saugus with steam as a by product.

Like all urban centers, Boston employs large volumns of process heat led by the fishing piers consumption of 40 T. To meet this need a new ice plant is being constructed on a nearby pier to supplement the single current supplier. The meat packers and produce warehouses consume large volumns of refrigeration such as Fulton meat packers with a total of 450 T.

Added to these are the multiplicity of cooling uses demanded by the 20th century such as drug and photo supplies, supermarkets and package stores and computer and telephone switching rooms.

Figure VI-10



UTILITY LINES

Prepared for

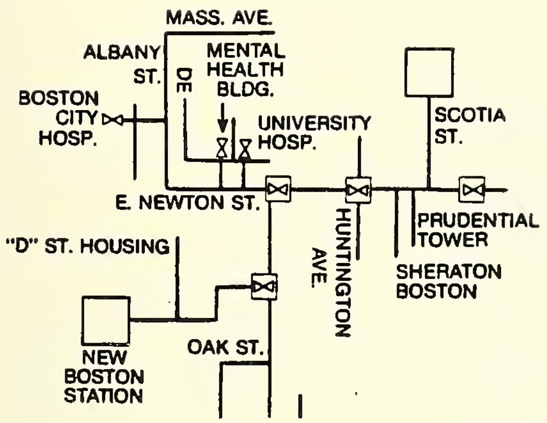
Massachusetts General Hospital
C.S.C.D.C.
Massachusetts D.P.H.

0 40 80 160 240 FEET

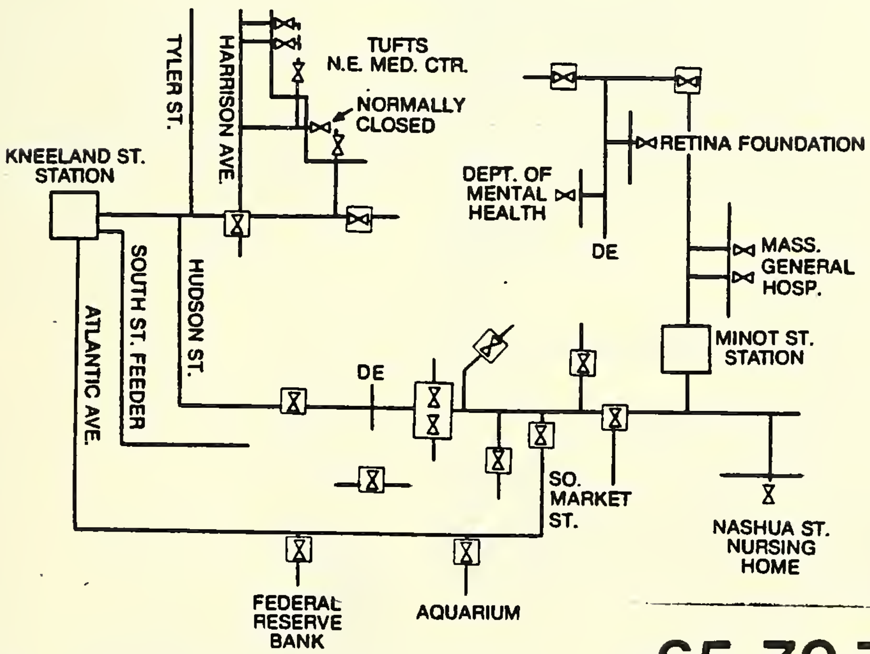
FEBRUARY

Among the largest customers are:

- Massachusetts General Hospital
- Boston City Hospital
- Northeastern University
- The Prudential Building
- The John Hancock Building
- Sheraton Boston Hotel
- Tufts Medical Center
- Boston City Hall
- "D" Street Housing Project
- The Prudential Apartments
- The Aquarium
- The Federal Reserve Bank
- The John F. Kennedy Building
- The Custom House
- Quincy Marketplace and the adjoining Faneuil Hall



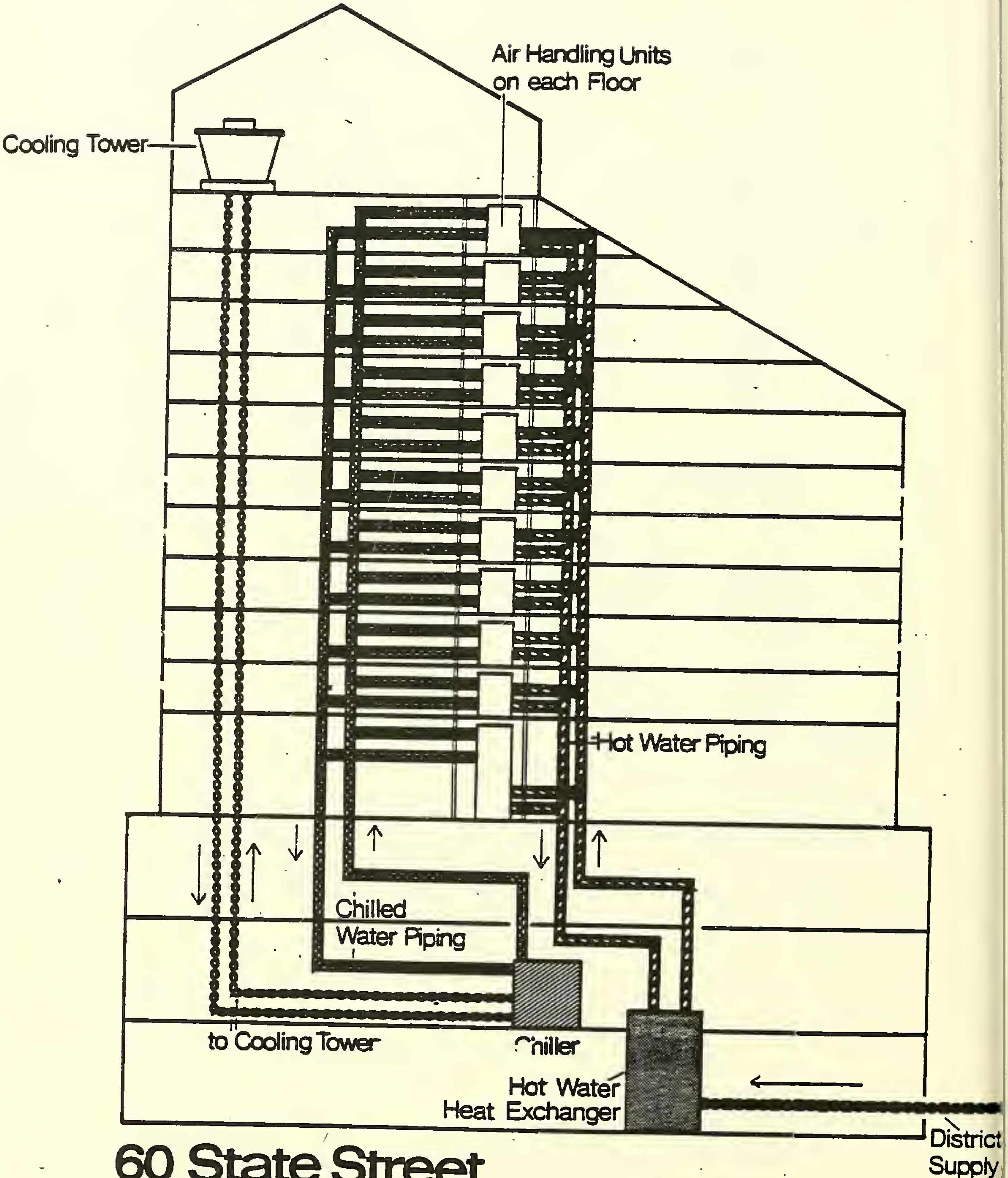
BOSTON EDISON District Heating System



65-70 Tons Cooling

Steam heat distribution system

The steam heat service area, limited to the City of Boston, extends West to Northeastern University, North to Massachusetts General Hospital, South to the "D" Street Housing Project in South Boston and East to the waterfront. There are approximately 22 miles of underground steam mains that serve 400 customers in this area.



60 State Street

Riser Diagram: Heating and Air Conditioning

Figure 3

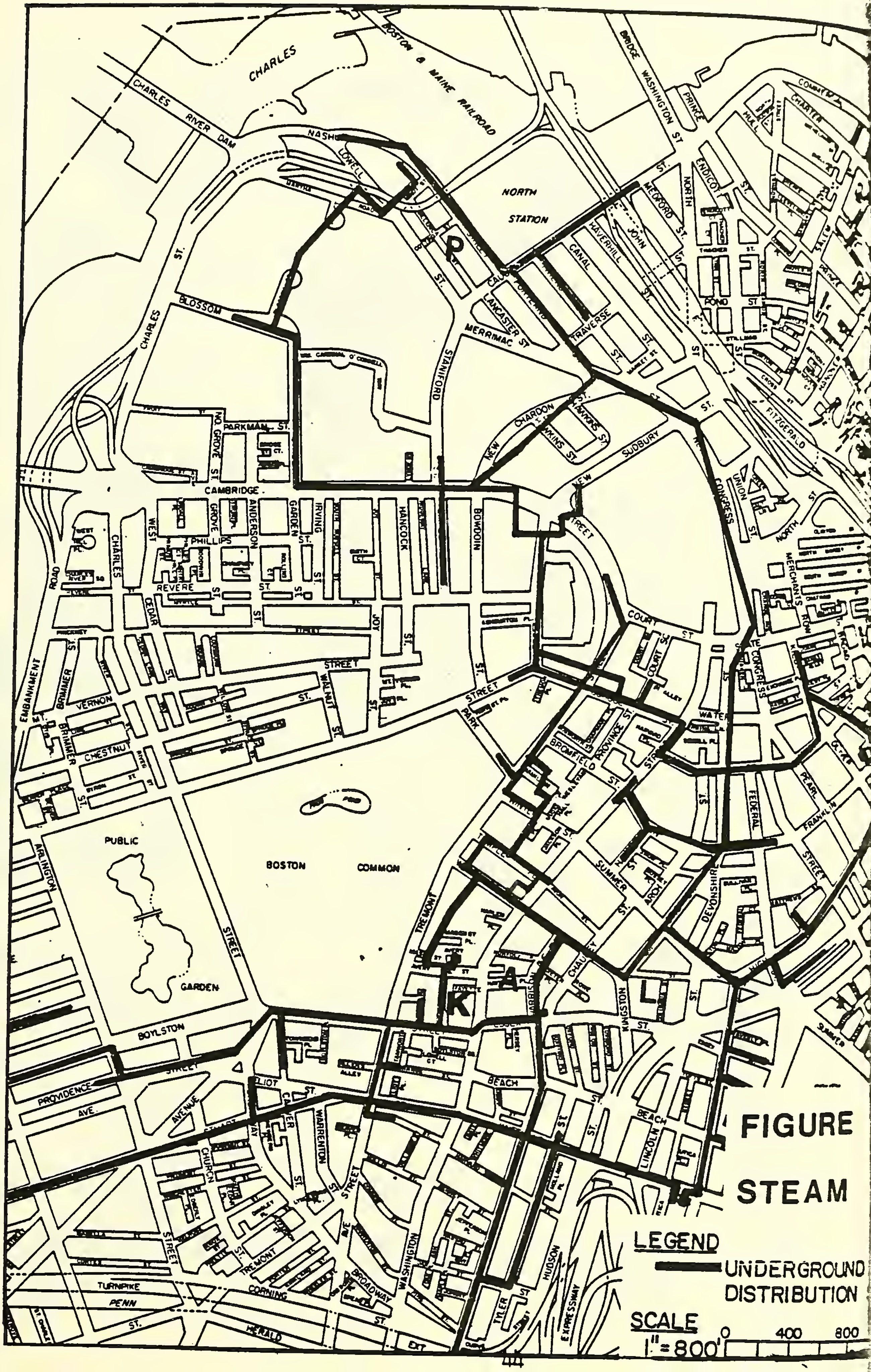
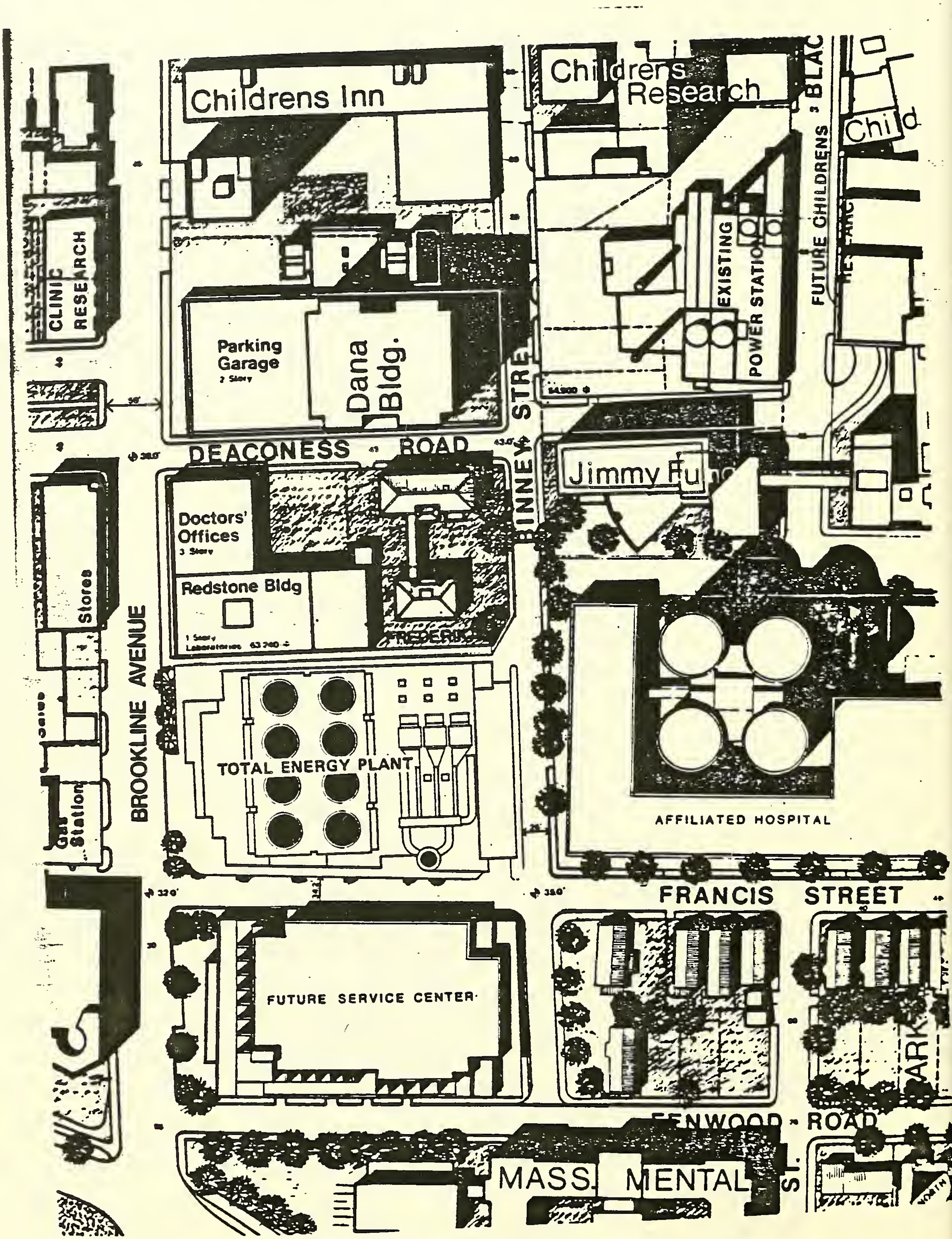


FIGURE
STEAM
LEGEND
UNDERGROUND DISTRIBUTION
SCALE
1" = 800'
0
400
800
CHARLES
CHARLES RIVER DAM
BOSTON & MAINE RAILROAD
NORTH STATION
BRIDGE
WASHINGTON ST.
PRINCE
NASHUA
LOWELL
CAUSEWAY
LANCASTER ST
MERRIMAC ST
CANAL
HAVERHILL
TRAVERSE
FRIEND
NORTH
ENDICOTT
SALEM
CHARTER
HULL
FITZGERALD
STANIFORD
BLOSSOM
CHARLES ST.
CAMBRIDGE
NEW CHARDON
SUDBURY
BOWDOIN
HANCOCK
GARDEN
GROVE
ANDERSON
IRVING
PHILLIPS
REVERE
CEDAR
WEST
JOY
EMBANKMENT ROAD
BRIMMER
CHESTNUT
VERNON
WALNUT
PARK
CONGRESS
UNION
MERCHANTS ROW
COURT
COURT SQ
STATE
WATER
BROMFIELD
PROVINCE
FEDERAL
PEARL
FRANKLIN
DEVONSHIRE
SUMMER
ARCH
TREMONT
CHAUNCY
HARRISON
KINGSTON
BOSTON COMMON
PUBLIC GARDEN
ARLINGTON
BOYLSTON
PROVIDENCE
ELIOT
CHARLES
CHURCH
WARRENTON
BEACH
LINCOLN
WASHINGTON
HUDSON
TYLER
EXPRESSWAY
BROADWAY
TURNPIKE
PENN
HERALD
CORNING
ST.
K
A
L
R



Childrens Inn
Childrens Research
Child
CLINIC RESEARCH
Parking Garage
2 Story
Dana Bldg.
EXISTING POWER STATION
FUTURE CHILDRENS
DEACONESS ROAD
BINNEY STREET
Jimmy Fu
Doctors' Offices
3 Story
Redstone Bldg
Stores
BROOKLINE AVENUE
TOTAL ENERGY PLANT
AFFILIATED HOSPITAL
Gas Station
FRANCIS STREET
FUTURE SERVICE CENTER
FENWOOD ROAD
MASS. MENTAL
ST.

MANUFACTURE OWN STEAM

MATEP

Centrifigal chillers with motor & condensing steam drives

6 cooling tower cells @ 11k gpm

15 K Tons cooling

BOSTON UNIVERSITY

3 new buildings(Absorption units)

3 units @ 500 Ton-	1500 Tons
2 units @ 350 Ton	700 Tons
	2200 Tons

Old buildings

50-100 Ton Trane units
Air cooled- top floors
Water cooled- lower floors

CHARLES RIVER PARK

4 boilers @ 3K lb.?hr.
Emerson,Whittier,& Hawthorn- 35K each
Cambridge St. and Plaza- 20K each

CHRISTIAN SCIENCE CENTER

2240 tons

ELECTRICALLY HEATED BUILDINGS
IN
THE CITY OF BOSTON

	KW DEMAND	KWH/YR.
1. Copley Place	25,000	56,000,000
2. Dewey Square Tower	8,000	18,400,000
3. Exchange Place	7,600	20,200,000
4. One Post Office Square	7,800	17,000,000
5. Department of Transportation	5,000	13,920,000
6. Back Bay Hilton	2,400	8,200,000
7. Devonshire-Milk Assoc.	1,400	4,655,000
8. Rice Building Trust	1,500	4,000,000
9. Ritz-Carlton Hotel	2,000	4,600,000
10. Liberty Square Trust	960	2,560,000
11. Suffolk University	1,625	2,740,000
12. Bostonian Hotel	1,200	3,100,000
13. Long Wharf Hotel	4,000	8,500,000
14. Berkeley Place	860	1,628,000
15. Channel Development	550	1,100,000
16. Harbridge House	160	365,000
17. Charles St. Meeting House	145	340,000
		670,979,000
		394,693.5 barrels
		78,020.8 [illegible]

RTW/nks
8-31-81

COPLEY PLACE

Electric heating and cooling

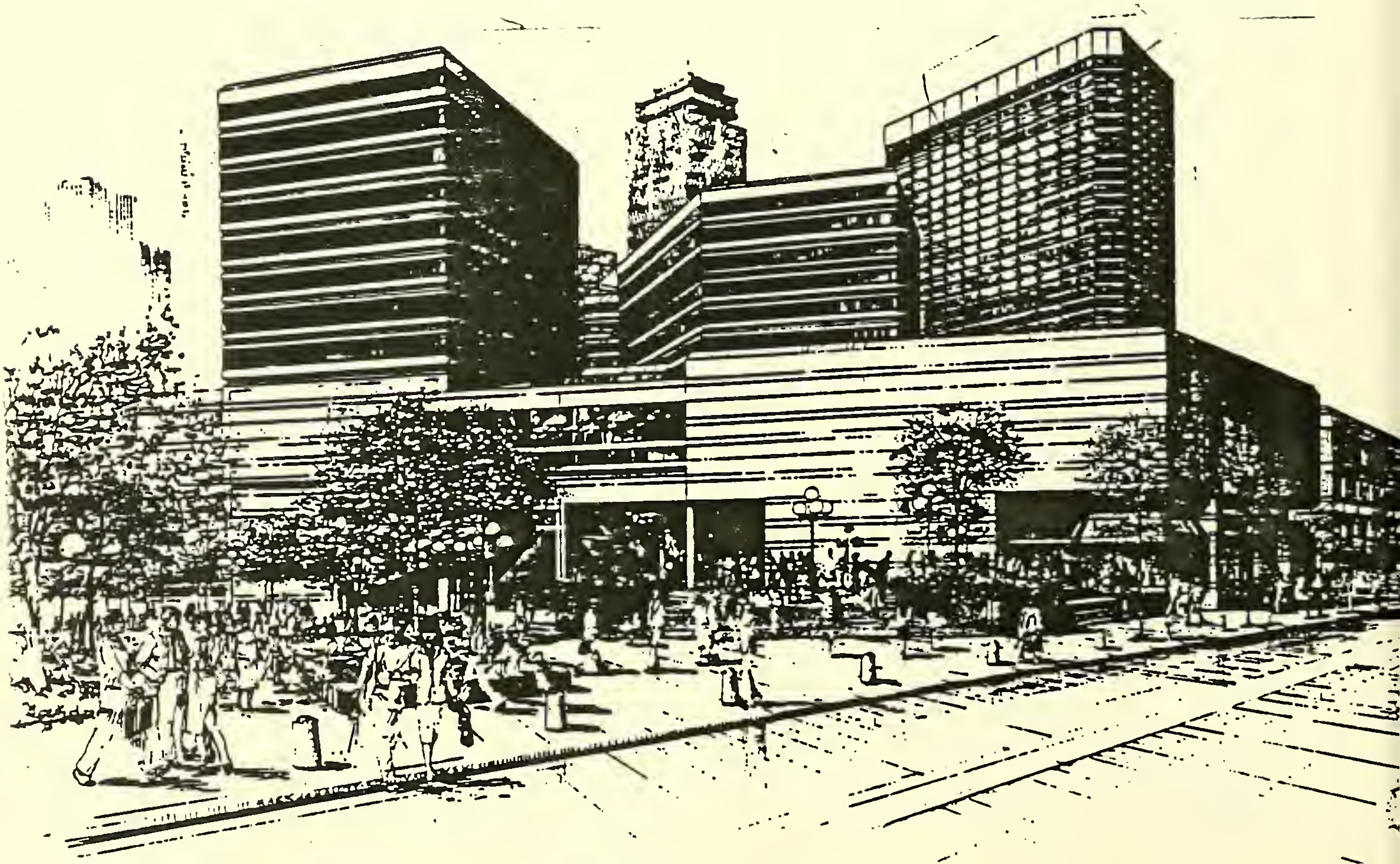
8 rooftop units- office tower
either cool or circulate fresh air(economizer)

Cooling load- 3K Ton
for central area (office & retail)

Retail Mall- 2 rooftop units
chilled water coils

Central plant for chilled water for entire complex
Electric drive chillers
6200 tons capacity
Central plant @ 100' level
under Huntington Ave.
Entrance in subterrean level between
R.R. & south ramp

Cooling towers- on office roof
each tenant in retail space gets chilled water &
5 kw/sq. ft. electric power(compatible system)



GENERAL SERVICE RATE G-3

Available for commercial and industrial use at a single location where service is supplied to the customer and metered at 14,000 volts nominal and where the customer furnishes, installs, owns and maintains at his expense all protective devices, transformers and other equipment required by the company. Not available for resale or for domestic service in residential premises.

Rate:

Demand Charge

During the billing months of:

July-October	November-June	
$757.00	$757.00	per month for the first 150 kilowatts of demand or any portion thereof.
4.93	3.91	per kilowatt per month for the next 650 kilowatts of demand.
4.58	3.56	per kilowatt per month for the excess.

Energy Charge

1.74 cents per kilowatthour for the first 290 hours' use of the demand per month.

1.56 cents per kilowatthour for the next 150 hours' use of the demand per month.

1.05 cents per kilowatthour for the excess.

During the billing months of July through October, all use will be billed an additional charge of

.63 cents per kilowatthour.

Fuel and Purchased Power Adjustment as provided in "Fuel and Purchased Power Adjustment," applicable to all kilowatthours on this rate.

Conservation Service Charge as provided in the "Conservation Service Charge," applicable to all bills rendered under this rate.

Determination of Demand: The maximum thirty-minute demand (either kilowatts or 80 percent of the kilovolt-amperes) will be determined by meter during the monthly billing period except, any demand recorded between 12 p.m.* and 9 a.m.* and all day Saturday and Sunday will be reduced by 70 percent. The number of kilowatts of demand billed shall be the maximum demand so determined, but in no case less than the higher of the following: (1) 150 kilowatts and (2) where Auxiliary Service is supplied, the Auxiliary Service Capacity. Demands established prior to the application of this rate shall be considered as having been established under this rate.

Minimum Charge: The demand charge for 150 kilowatts.

CONVERSION TO ELECTRIC COOLING
FROM INEFFICIENT ABSORPTION UNITS

BOSTON CITY HOSPITAL

Electric turbine is being installed
Will soon be on electric cooling

JOHN HANCOCK TOWER

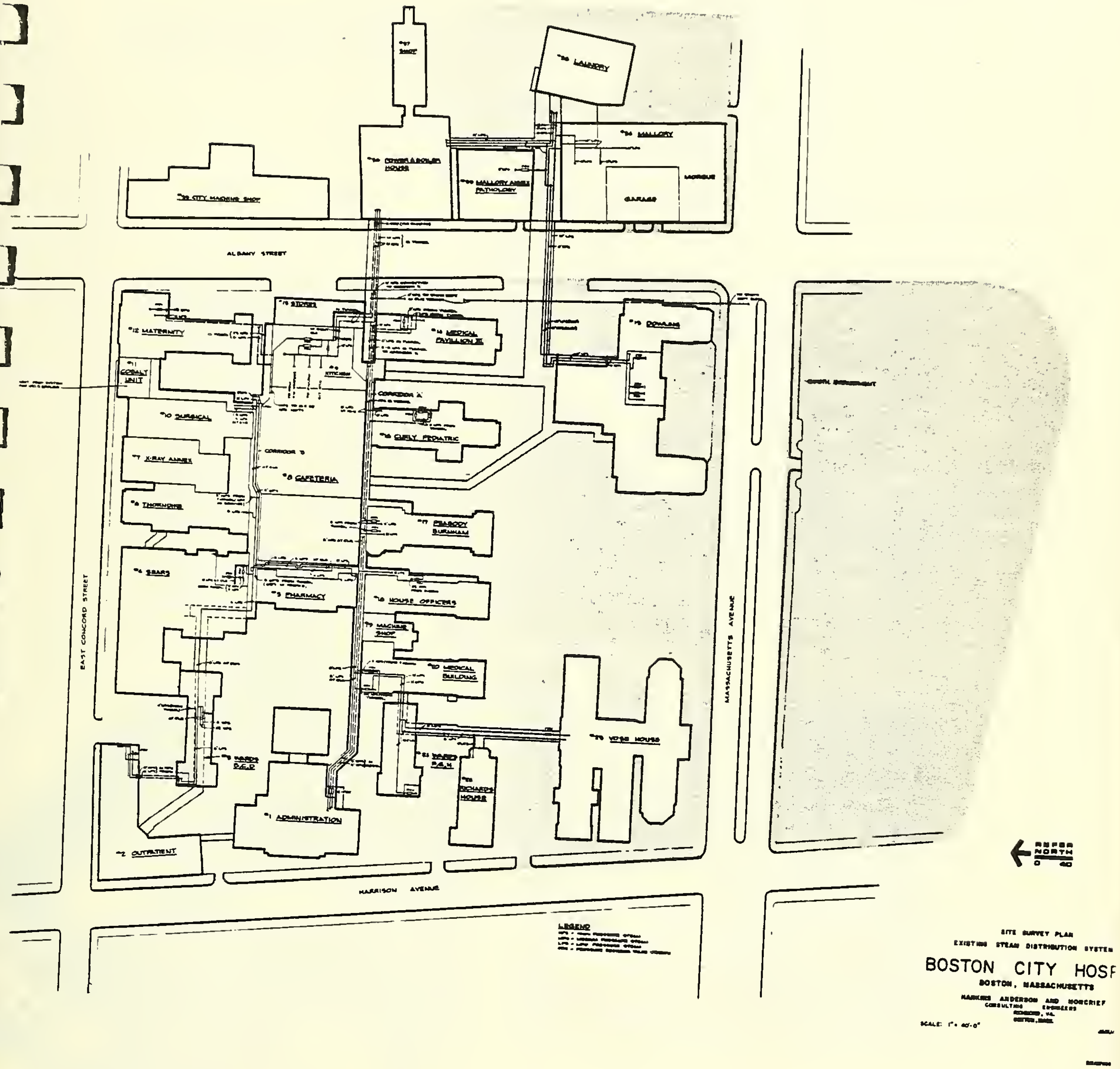
Building divided into two halfs
2500-3000Tons centrifigal chillers each half&
small electric centrifigal chiller
of 300-400 Tons

Installing a 1000 Ton electric centrifigal
to bottom half

NORTHEAST_ERN (40-50 buildings)
TAKING OUT Boston Edison steam
Absorption units.

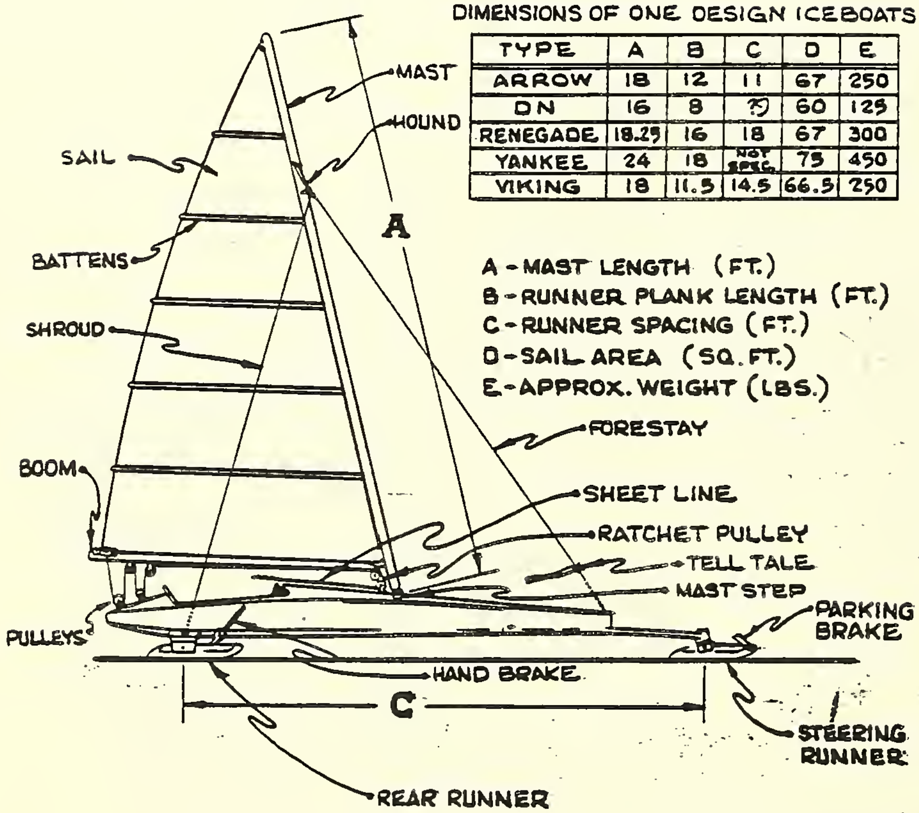
Replacing with centrifigal
reciprocating electric units

ETC.ETC.ETC.



EXISTING STEAM DISTRIBUTION SYSTEM

PRINCIPLE PARTS OF AN ICEBOAT



DIMENSIONS OF ONE DESIGN ICEBOATS

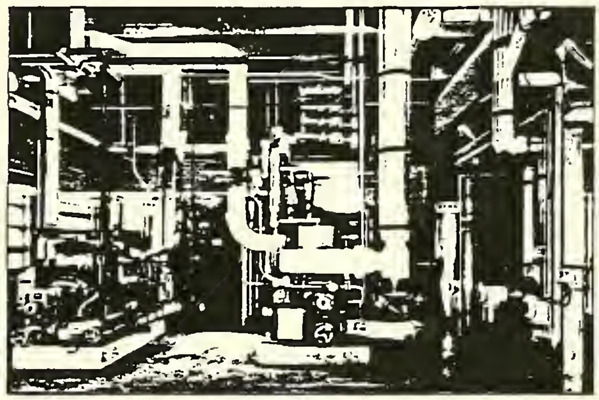
TYPE	A	B	C	D	E
ARROW	18	12	11	67	250
DN	16	8	[illegible]	60	125
RENEGADE	18.25	16	18	67	300
YANKEE	24	18	NOT SPEC.	75	450
VIKING	18	11.5	14.5	66.5	250

A - MAST LENGTH (FT.)
B - RUNNER PLANK LENGTH (FT.)
C - RUNNER SPACING (FT.)
D - SAIL AREA (SQ. FT.)
E - APPROX. WEIGHT (LBS.)

Sports

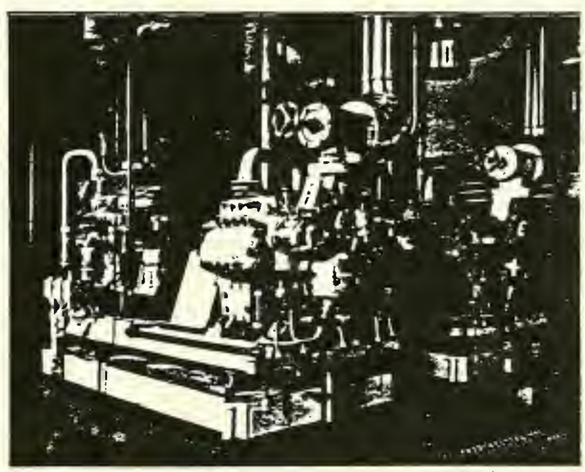
Industrial refrigeration.

Dairies



Food processing and cold storage

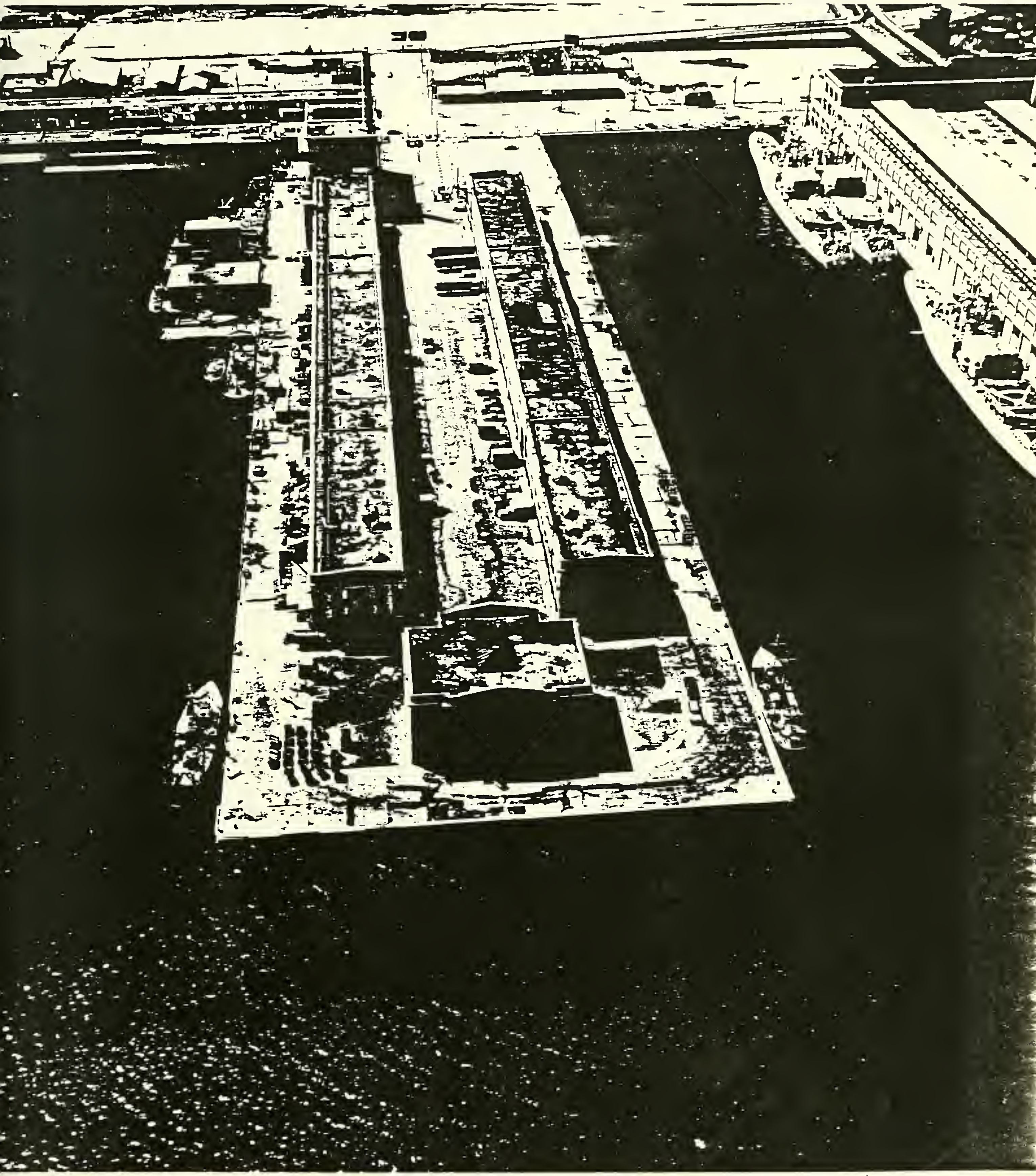
Breweries



Chemical and allied industries

Computers

Photographic



FISHING INDUSTRY

Boston Fish Pier Renovation 250,000 s.f.

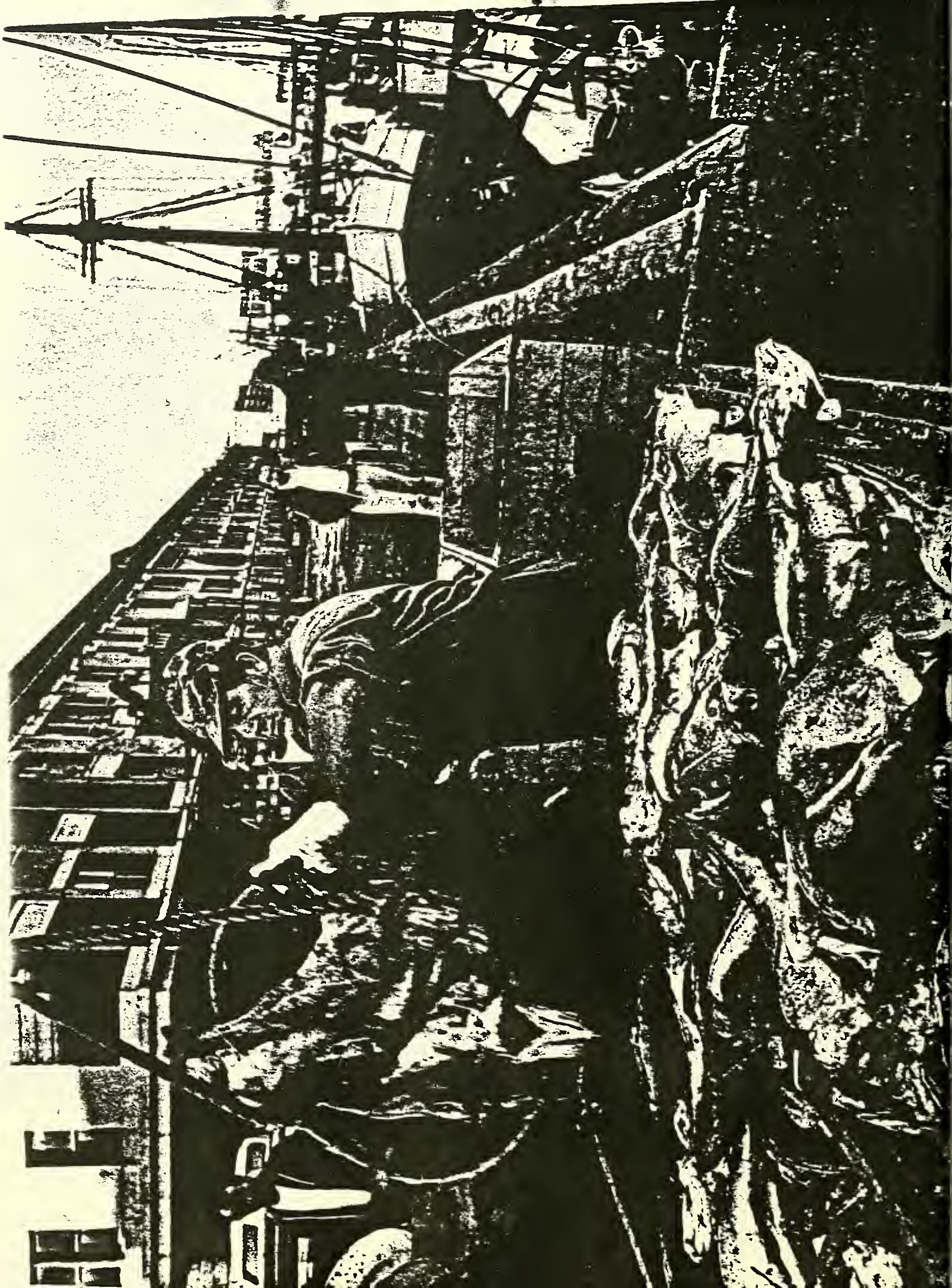
MASSACHUSETTS PORT AUTHORITY

Boston, Massachusetts

SYMMES, MAINI & McKEE

Architects, Engineers and Planners

Cambridge, Massachusetts



NEWER TECHNOLOGIES

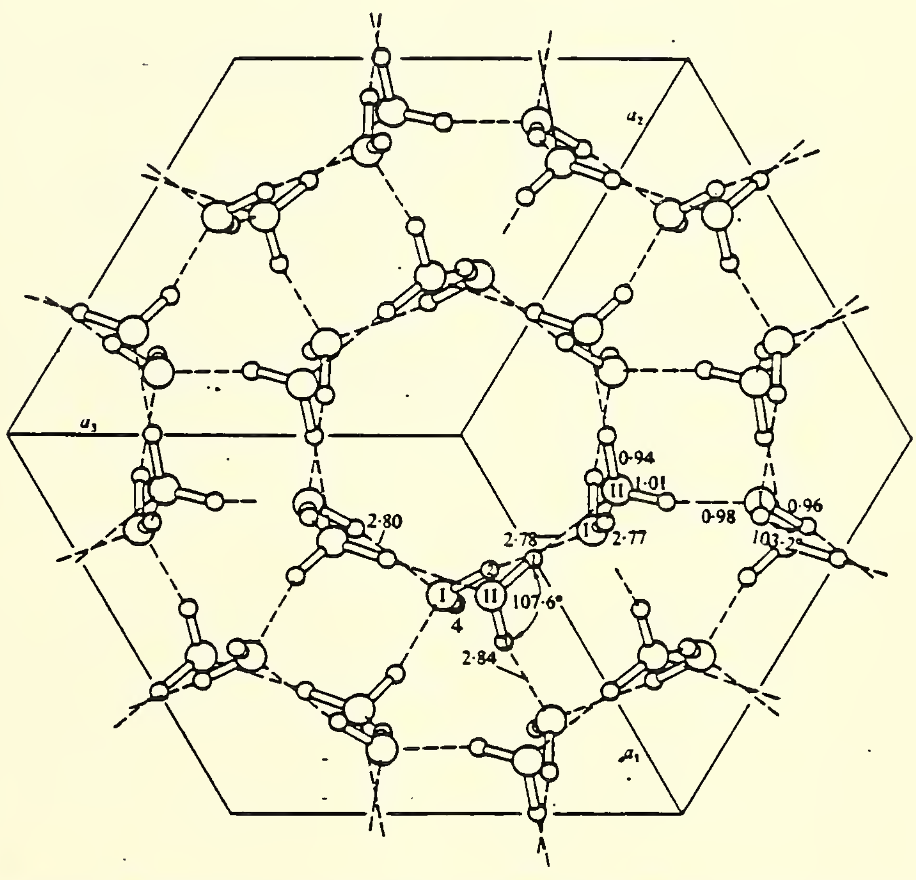


FIG. 1.19. Structure of ice II, viewed along the hexagonal *c*-axis. Hydrogen bonds between the water molecules are shown as dashed lines. Lengths are in Å. Each puckered hexagonal ring consists of water molecules of one of the two non-equivalent types, as indicated. Rings of the two types, stacked alternately one above the other, are linked together into columns by hydrogen bonds in the same way as in ice Ih. Adjacent columns are linked together in a more tightly fitting way than in ice Ih. Measured bond distances (in Å) and angles are indicated. From Hamilton *et al.* (1969).

THE NEW ICE TECHNOLOGIES

Sources

Natural - snow removal
icebergs
shipping channel clearing

Mechanical - by product of heat pump (ice maker-heat pump)

Semi/mechanical - ice builder, ice island, heat pipe, ice maker, snow gun, snow box

Cooling Systems

Daily Peak Shaving - running refrigeration equipment during the night and removing heat from storage medium (chilling or freezing water) saves on daytime peak electric rates

Weekly Peak Shaving - often used in past for churches and dairies. By storing cold in ice a much smaller compressor could run all week and function for the short user period

Annual Storage - a system which stores the cold of winter and utilizes it for cooling in the summer

Storage Mediums - water (1 BTU to raise 1 lb., 1° F
ice (144 BTUs to melt 1 lb. of ice)
Phase change material - salty water; raises specific heat

Auxilliary Uses - water supply, desalinization, purification, structural, insulation, enhanced transmission of sound and electricity.

SOURCES OF ICE

Should we manufacture or harvest this large amount of cold necessary for todays cooling. Among natures more prevelant sources and often a liability if not removed is the snow and ice which clog our transportation routes, namely our urban streets and sidewalks, our shipping channels and even our airport runways. Underground aquifers and icebergs are other sources. The most common method of manufacturing the product utilizes the characteristics of refrigerants (gases which boil at a lower temperature than water i.e., freon, ammonia, SO^2 and CO^2). These substances having been compressed to a liquid state will absorb a lot of heat when expanding back to a gas. Ice can be formed in innumberable shapes, blocks, cubes, cylinders, flaked, chipped, slush, etc. Some form of metal container, cylinder or plate is often employed.

Among the more promising ways of producing this cold sink is by letting nature give a boost to the energy intensive manufacturing process. By running a regular brine operation in the winter, the bulk of freezing is free. Many coil systems and heat pipes (such as Argonnes and "ICES") can transfer winter's cold to a large insulated volumn of water.

Other possibilities lie in letting technology increase the speed of natural processes. Speeding up the ice cover on the ocean is done by the Army with submersible pumps while others, (Northby of R.I.) spray the surface of the block to speed ice growth. Princeton utilizes the "snow machine" while many types of "snow boxes" capture the winter winds to mix with water vapor and moisture sprays.

Also hopeful are the systems based on coupling the heating and cooling loads such as the ACES system developed at Oak Ridge where the ice is a by product of the heat pump in winter.

TABLE 5. COOL STORAGE SYSTEMS

System	R&D Group	Operation Mode	BTU/ft^3	Testing	Cost $/million BTU)	Remarks
Cool water storage	in use for many years; membrane developed by R. Tamblyn, Ontario	coupled to chilled water system	1250, 20°F temperature differential	many installations	3000-6000	larger volume requirements limited ΔT
Rolling cylinders with Glauber salts	General Electric	air side storage	1870, 50% maximum packing density	laboratory	unknown	best suited for small commercial and residential
Glauber salts in bags	Massachusetts Institute of Technology	decentralized storage, air charge	3500	500 ft^2 test space	12,000	for use in interior zone of large commercial structures, may be charged with cool ambient air
Microencapsulated paraffins	General Electric	coupled to chilled water system	1750, 50% maximum packing density	laboratory	14,200	encapsulating material needs strengthening
Ice maker Heat pump	Oak Ridge National Laboratory	coupled to chilled water system	5280, 50% maximum packing density	40,000 ft^2 office, largest installation known	8900	equipment is twice as expensive as packaged chillers
Pipes in tank ice system	Wisconsin Electric with A. O. Smith Corporation	coupled to chilled water system	8100, 85% maximum packing density	residential tests conducted by Wisconsin Elec.	4400 (120 gallon tank)	major cost is pipe in tank

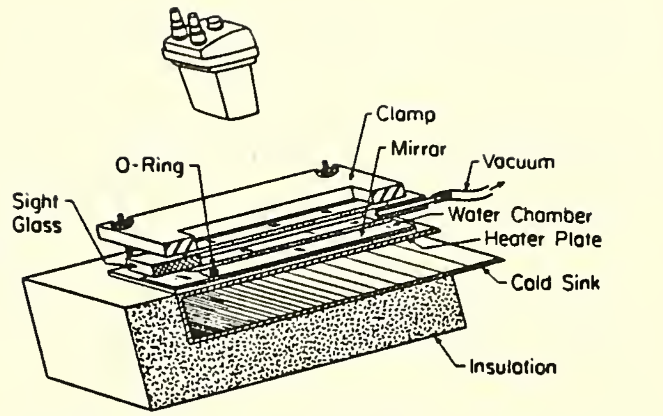


Fig. 1. Schematic diagram of freezing apparatus.

Artificial ice production

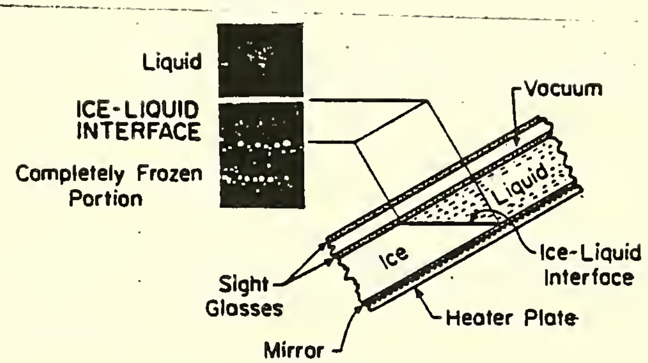
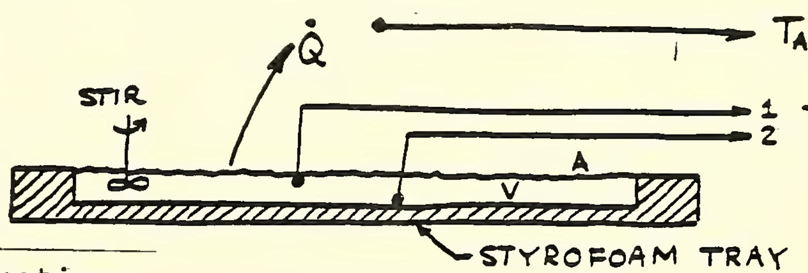


Fig. 2. Schematic illustration of the solid-liquid interface position in the photographs.



Northby's in situ ice production
in Rhode Island

FIGURE 2a: Schematic of Heat Transfer Experiment

44 BTUs to melt 1 LB. Ice

1 ton Ice = 12K BTU / Hr.

288 K BTU / Day

1 TON Ice = 2000 LB

1000 Kilograms - 1 Metric Ton

kilogram = 1.102×10^{-3} tons

Kilogram = 2.2046 LBS.

1 cu Ft. Water = 62.5 lb.

1 cu Ft. Ice = 57.5 lb.

1 gal water = 8.3453 lb.

1 lb. water = .1198 gallons

1 lb. water = .01602 cu FT.

1 cu FT = 7.481 gallons

661 Cooling °Days in Boston

67 Ton days of cooling

19.3×10^6 BTU

$5.65\ 10^3$ kw Hr

8880 Freezing hrs. in Boston

1 BTU = 2.928×10^{-4} kilowatt hrs

1 BTU = .00029287 Kilowatt hrs

1 kilowatt hr = 3415 BTUs

1 BTU / min = .01757 Kilowatt

1 kilowatt = 56.92 BTU / min

3415.2 BTU / Hr.

1 BTU = 1054 joules

MJ = .278 KW

= 948 BTU

1 Kilowatt hr = 3.6×10^6 joules

District Cooling ESTIMATE

1 TON - / 400 □

72 BTU / □

18 Lb. STEAM / ton Cooling

1.2 kwh / ton Cooling

3400 BTU / Ton Cooling

DAILY STORAGE

Quinlan's Ice Storage
for daily peak shaving

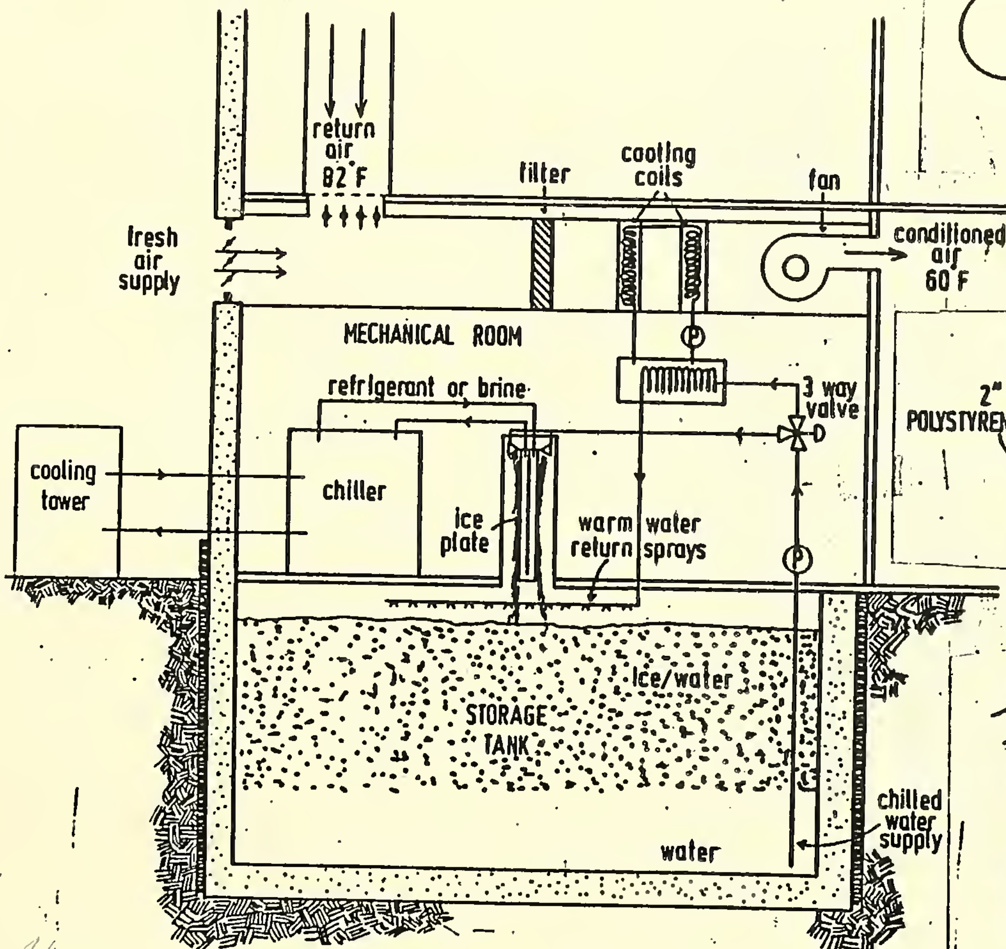


FIG 37
ICE STORAGE USING A FROSTLESS ICE PLATE

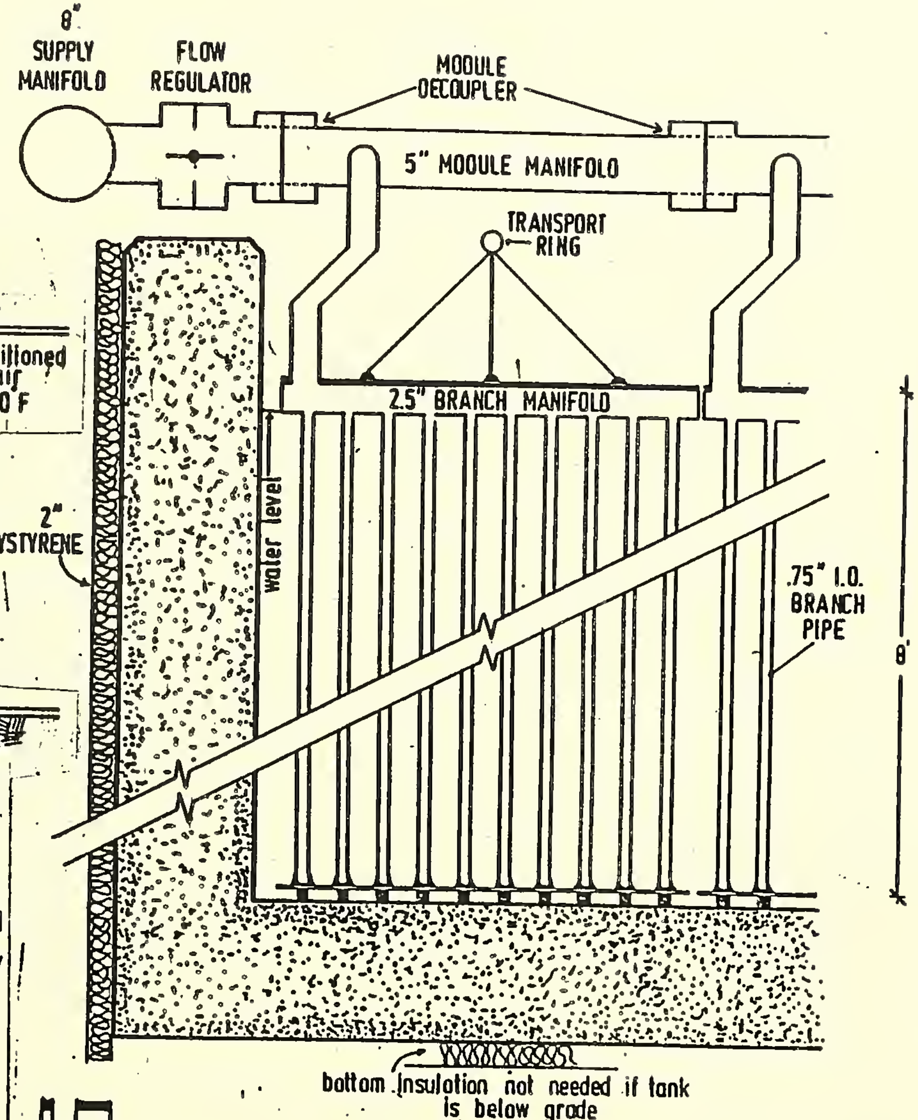


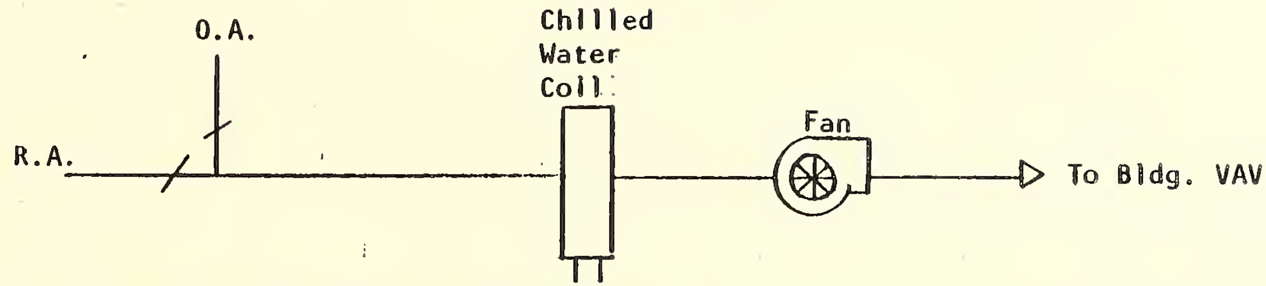
FIG 35
SECTION 'a' THROUGH
ICE STORAGE TANK

As our cities become more dense and develop sophisticated economies, the use of electric power becomes more uneven with the summer midday consumption at an enormously higher level. With todays construction costs, regulatory delays and the high cost of money, building new generating stations becomes more and more difficult. Consequently many power companies offer incentives and/or preferential rates for off peak usage. The breakdown of the average utility bill includes a "demand charge which reflects the largest amount consumed at once and a time of day rate which depends on the time of day of consumption. The highest penalty for mid summer use occurs in New York City while some mid west cities operate at the same rate. Some companies offer special "J" rates to encourage off peak consumption rates which can reach as low as one sixth of the cost of peak rates. Therefore, there can be enormous benefits to peak time consumers to utilize the newer thermal storage technologies, particularly in the northeast where basic utility rates are quite high. Some of the more dramatic examples of the daily thermal storage for single buildings are the new Tishman-Speyer office tower on Park Avenue, New York with 1.4 million gallons in tanks shifting all the cooling operation to night time for the 40 story structure, the 52 story placid oil building in Dallas with 700k gallon in 31 tanks, and the 1.2 sq. ft. state of Illinois center in Chicago with 200k gallon of ice storage capacity cutting the electric bill in two.

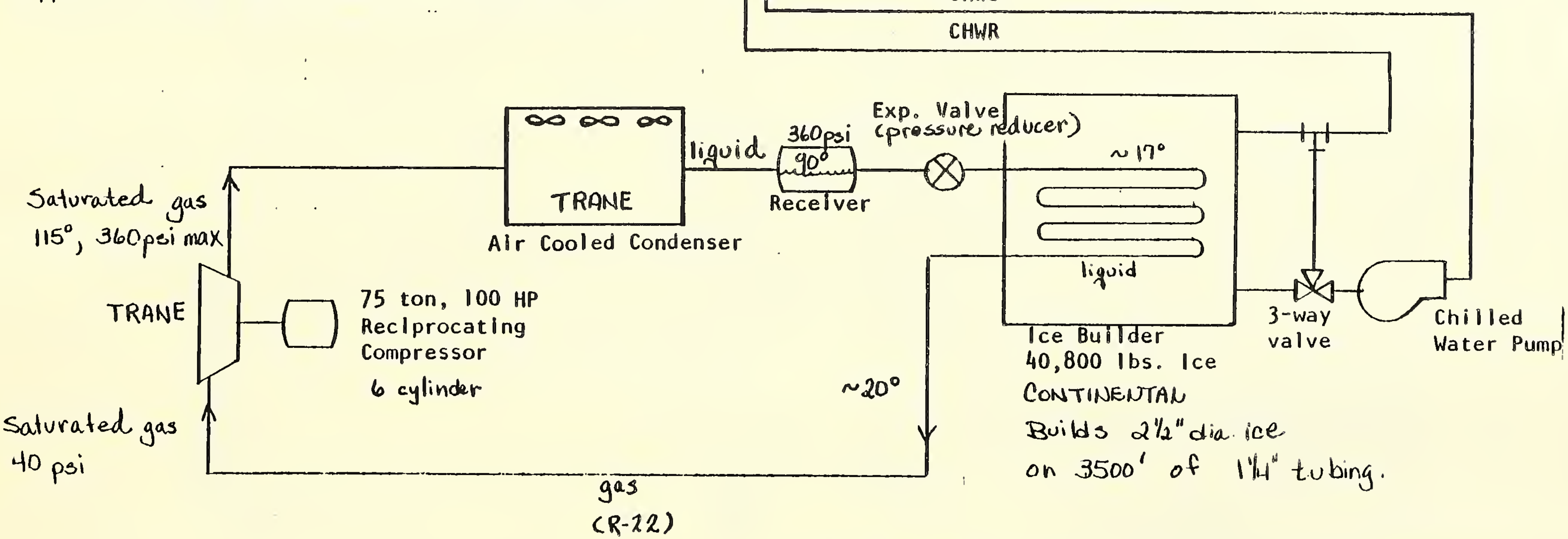
New commercial structures can choose from a range of options varying from total shifting of condensor operation to a partial load leveling depending on the individual area's time of day rates and the amount of storage space available. concurrently, many utility companies are sponsoring programs for groups of individual homes to take advantage of off peak usage; Long Island lighting installed 250 lb. water storage tanks in 50 homes while Wisconsin electric modified the 120 gallon water heater tanks in 70 homes with evaporator coils. As more utility companies offer special rate structures and incentives for off peak usage, it becomes more and more economical to install some kind of thermal storage system for both seasons which can eliminate the need for any boiler and cut the cooling cost in half.

BOLINGBROOK DISTRICT HEADQUARTERS

Ice Storage System



Commonwealth Edison has installed a thermal cold storage system at the new Bolingbrook District Headquarters building. The system consists principally of an ice making machine which will provide "all" the cooling for the building using off-peak electricity supplied from our nuclear and coal-fired base units.



This system will reduce the building's peak period demand by 69 KW and shift most of the air conditioning KWH to off-peak period.

The system consists of a 75-ton reciprocating compressor, air cooled condenser and a 40,800 pound ice bank. This system

Ice one

IPS Headquarters, Sioux City, Ia

In its new corporate headquarters, a public utility commits itself to energy-saving and to external and internal contributions to both its town and employees.

ELSIK HIGH SCHOOL

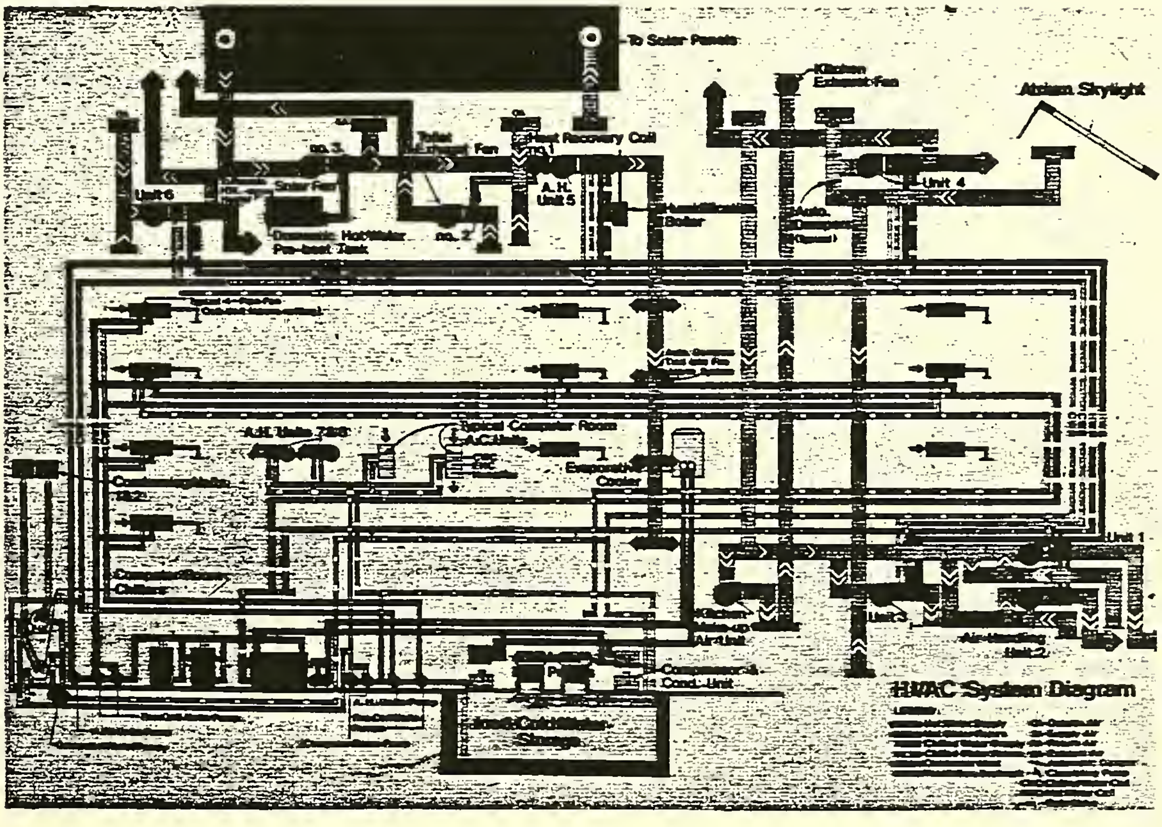
495 K

cuts peak energy by 45%

4K PVC pipes - 20' long & 6" Diameter suspended in large tank

600K gal - water glycol mix circulates in tank around frozen pipes chilled to

31 gal of water inside each pipe frozen



ICE STORAGE, THE COOLING SYSTEM THAT BENEFITS CUSTOMER AND UTILITY

K. Pientka, Commonwealth Edison

(Compiler's summary of oral presentation)

Mr. K. Pientka stated that the increased demand for electricity in the summer experienced by many utilities can be traced to the extensive use of air conditioning. "This temperature sensitive load has forced utilities to invest in plants that are only necessary for a short time each year. As a result, sharp increases in summer demand rates have to be applied by utilities. These higher summertime charges has caused the cost of air conditioning a building to rise at an accelerated rate when compared to other space conditioning costs. Therefore, the economic incentive for both the utility and their customers to reduce peak cooling demands has become more pronounced with each cooling season. A cooling system that could generate cold BTU's during periods of reduced electrical demand, and then store these cold BTU's for use during peak periods would benefit the utility by reducing peak systems loads, and benefit the customer through reduced cooling costs resulting from lower demand charges.

"Attempting to find a positive solution to this negative and growing trend Commonwealth Edison Company, the electric utility that serves approximately the northern one-third of Illinois, including Chicago, has embarked on a marketing program to promote the concept of ice storage to both new and existing customers. This program has been implemented to help reverse the trend of a declining system load factor by shaving peak demands and to increase the use of electricity in off peak periods. The program is tailored to the company's generating characteristics. Currently, Commonwealth Edison's base load is generated almost exclusively by low-cost nuclear and coal-fired generatng stations. The daytime peak load is met with the use of less efficient coal plants, high cost oil-fired generation, and peaking units. The shifting of kilowatt hours to off peak periods with ice storage will allow Commonwealth Edison to supply a much larger percentage of a building's cooling energy requirements with the company's efficient base-load units."

An ice storage system is now being incorporated into the plans for a three story 68,000 ft^2 (6,300 m^2) office building for the Federal Life Insurance Company.

"The ice storage system was designed by Globe Engineering Company of Chicago, and is being installed by Borg Mechanical Contractors, Inc. of Hillside, Illinois. Two 45-ton reciprocating compressors; two evaporative condensors, each having a 10 horsepower fan and a 1½ horsepower pump; and two 80,000-pound ice builders, each having a 5 horsepower agitator, are included in the system. On design days it is expected that the system will have to operate 16 hours per day to meet the maximum daily cooling requirements of 1,220 ton-hours. During the entire cooling season it is expected that only off-peak compressor operation will be required to meet the building's cooling needs. Since the demand created by the storage system is less than the normal daytime demands, no demand charge is incurred for the operation of this equipment."

"Federal Life's ice storage system will have replaced a conventional 200 ton chiller at no additional first cost to the owner. It is estimated that the peak cooling demand, including auxillaries, will be reduced from 259 kilowatts to 143 kilowatts, and the peak billing demand reduced from 259 kilowatts to 7 kilowatts. As a result of this lower billing demand, an annual demand charge savings of $7,080 is expected. This savings equates to a 41% reduction in the total cooling bill. The estimated savings are based only on a reduction in the demand charges. However, the potential for reduced cooling energy consumption with this system may be realized through more efficient compressor operation and lower nighttime condensing temperatures."

"In addition to providing many user benefits, the ice storage cooling system can be advantageous to electric utilities because of its load leveling characteristics. Ice storage will allow utilities to reduce their system peaks, and to more intensively use their existing generation, transmission, and distribution facilities. One way to measure how intensively existing facilities are being used is load factor. In the case of Federal Life Insurance, it is estimated that by reducing its peak demand by 116 kilowatts, the seasonal load factor for the entire building will be improved from 29% to 37%, and that the seasonal load factor on the air conditioning system will be increased from 19% to 35%."

"The reduction in peak cooling demand also results in increased energy consumption in off peak periods. Therefore, the utility is allowed to meet a larger portion of the building's cooling energy requirements with efficient, low cost, base load generating equipment in lieu of high cost peaking units."

"Installation of an ice storage system appears economically advantageous for both the user and the utility. The user benefits from reduced cooling costs, while the utility benefits from lower peak system loads and increased use of electricity in off peak periods. More importantly, the utility's long range advantages are estimated to be even more substantial. If enough ice storage systems are installed, a utility's peak system load growth could be reduced to the point where the commitment to a new generating plant could be delayed or deferred."

Quotations given above are from tape recording of Mr. Pientka's presentation. The interested reader is referred to paper given by Mr. Pientka:

Ice Storage - The Cooling System that Benefits
Customer and Utility

K. Pientka

To be published in
Electric Energy Management News
August-September 1981

Delete Fed Life 1-5

Cooling buildings with ice has been ~~brought~~ back in more sophisticated forms

The main advantage of cooling buildings with ice storage is that, potentially, the storage tank volume might be only 25 per cent of that required for water, but this is not always realized in practice. The reason smaller storage is possible is that it takes 144 Btu to melt a pound of ice, whereas raising the temperature of a pound of water by 1 F absorbs only 1 Btu. The ice storage applications in existence are of modest scale, though the approach is being considered for a 52-story office building in Dallas to be owned by the Placid Oil Company, which may use 31 steel storage tanks providing a capacity of 93,000 cu ft or 700,000 gallons, or about ½ gallon per sq ft. Because the tanks would be installed below ground on floors provided for car parking the designers wanted to reduce the area for thermal storage.

Ice-storage systems also can be used to provide hot water for space heating and domestic water by recovering the heat rejected in making ice. For the process to be regenerative, the ice has to be melted either with the heat recovered from lights, people and equipment, or from an auxiliary source such as solar heating panels.

The cost of ice-storage refrigeration equipment is about at a standoff in comparison with that for water storage. Efficiency of the refrigeration equipment for making ice, on the other hand, is from 33 to 40 per cent less than that for making chilled water because of the larger temperature range over which it has to work.

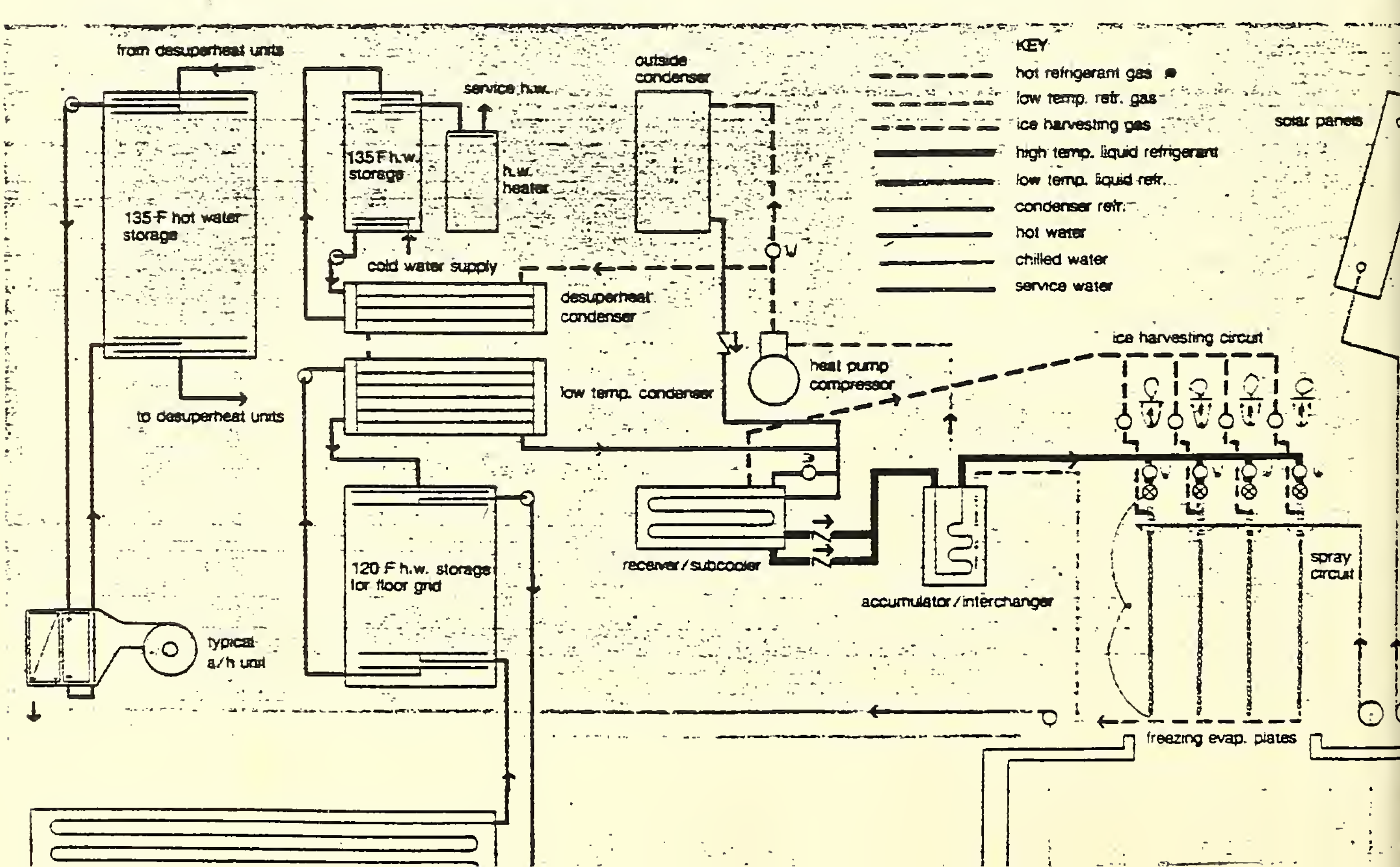
There are basically two types of ice forming systems. One is the ice builder, in which ice is built up around pipes or grids of tubing mounted in a water tank. The other is the ice maker, in which thin layers of ice are frozen when water is sprayed on evaporator plates. The system removes ice periodically by running hot refrigerant through the plates so that ice will drop off into a tank. With these systems, the tank may need to be as large as that for water storage if the size of the ice maker requires it to make ice over the weekend to meet the next week's needs.

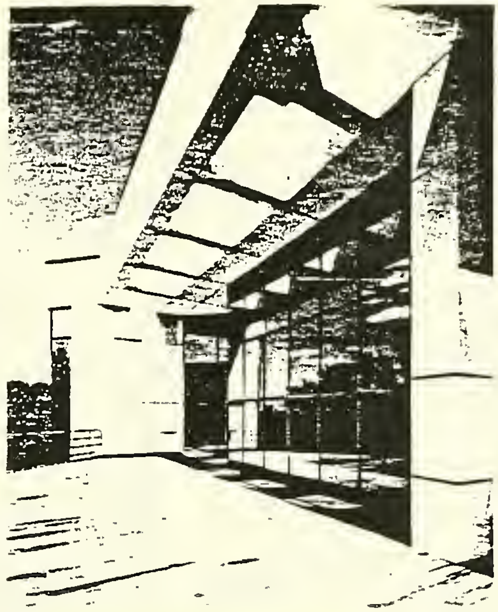
One place where ice-type storage systems are being tried out for off-peak cooling is in houses in a program initiated by DOE. The Long Island Lighting Company, for example, has installed ice storage systems in 50 existing houses. They are retrofitted with an ice-storage module, roughly 4 ft in diameter and 4 ft high, that can make 2,500 lb of ice.

Another utility, Wisconsin Electric[...] has installed ice-storage systems in 70 [...] and is using 25 other houses with conv[...] al systems for comparison. The storag[...] ules are 120-gallon water-heater tan[...] have been fitted with evaporato[...] instead of electric heating elements.

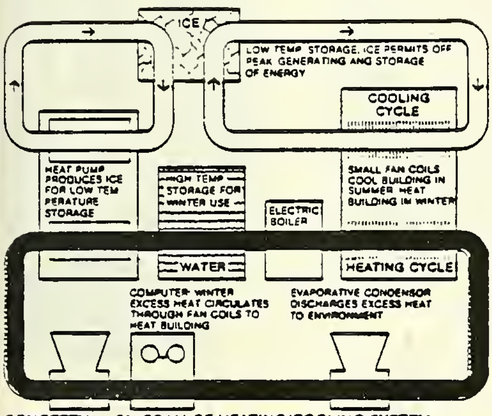
Examples of ice storage in building[...] larger than these houses include a [...] sq-ft vocational and technical sch[...] Reedsburg, Wisconsin (diagram, page [...] 40,000-sq-ft office building design[...] Architectural Alliance for Cray Rese[...] manufacturer of scientific computers i[...] dota, Minnesota, and a demonstratio[...] ect for the Veterans Administration-[...] bed nursing home in Wilmington, De[...] (RECORD, November 1976).

Packaged ice-maker heat pumps—which [...] thin sheets of ice on plates and slough [...] bins—have been used recently in several [...] er-scale buildings. The diagram below illus[...] the operation of this type of system fo[...] 16,800-sq-ft Madison Area Technical Coll[...] Wisconsin (photo previous page). Three 1[...] ice-maker heat pumps operated off-pea[...] designed to provide the heat for the bu[...] and the service water. Capacity of the ice [...] 3,800 cu ft. Excess ice accumulated durin[...] heating season is melted by heat from [...] panels on the roof.

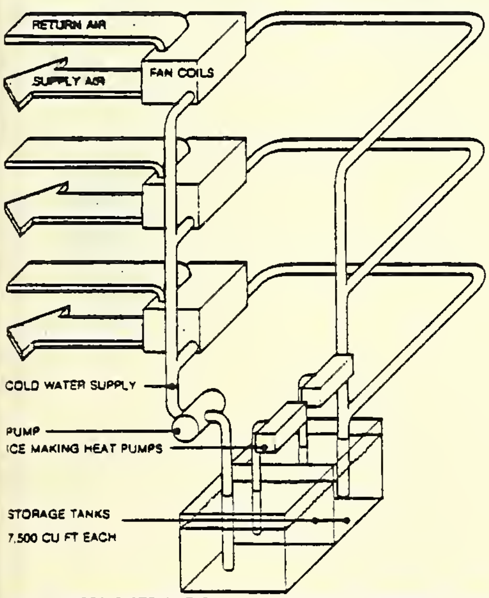




A main entrance to the building.



CONCEPTUAL DIAGRAM OF HEATING/COOLING SYSTEM



COLD WATER DISTRIBUTION DIAGRAM: CRAY RESEARCH BLDG.

The diagrams above explain the concept of ice storage as it is applied to the Cray Research, Inc., building. Being able to make ice at off-peak hours reduced electrical costs significantly. The ice itself reduced both the cooling machinery and the area needed for it in the building and ultimately resulted in energy savings over conventional systems.

GRAY RESEARCH INCORPORATED BUILDING

40K sq.ft. building-manufacturer of scientific instruments in Mendeta, Minnesota

Distributes energy evenly over 24 hour period via

2 Turbo ice making refrigeration machines with evaporative plates suspended over tanks drop 4'x6' sheets of ice into tanks.

5,000 cu.ft.concrete storage tanks divided into two halfs(to permit repair)
Tanks hold 115 gals. of water and are lined with 2" polystyrene.

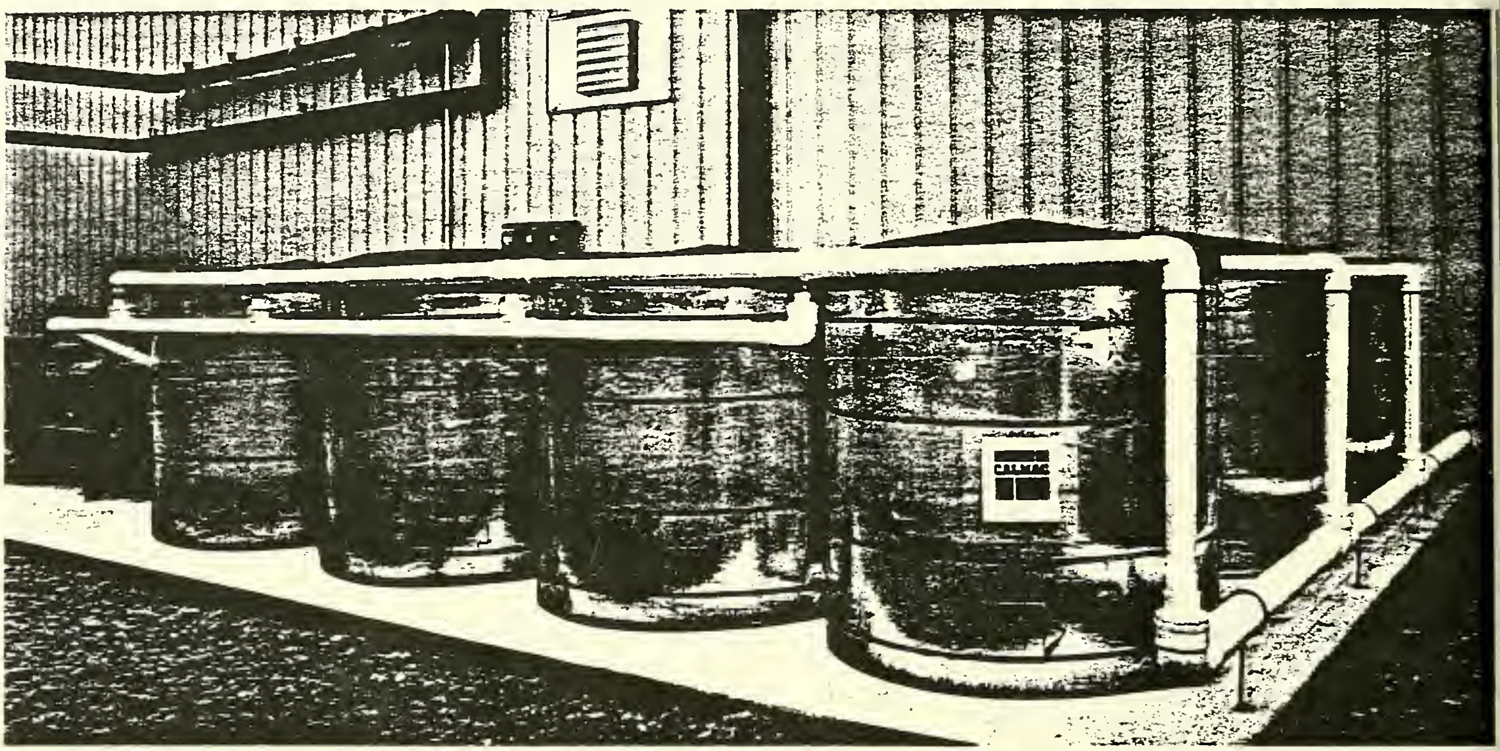
To prevent clogging of ice around cold water supply lines a 14" perforated PVC tube is placed over water intake line.
Water is treated to prevent corrosion.

Gray system is designed at 3 gal water/sq. ft.

Distribution system- 26 fan coil units placed throughout ceiling plenums of the buildings.
Each fan coil is connected to hot & cold water lines to provide for heating or cooling.

COMMERCIAL UNITS

IceBank-32



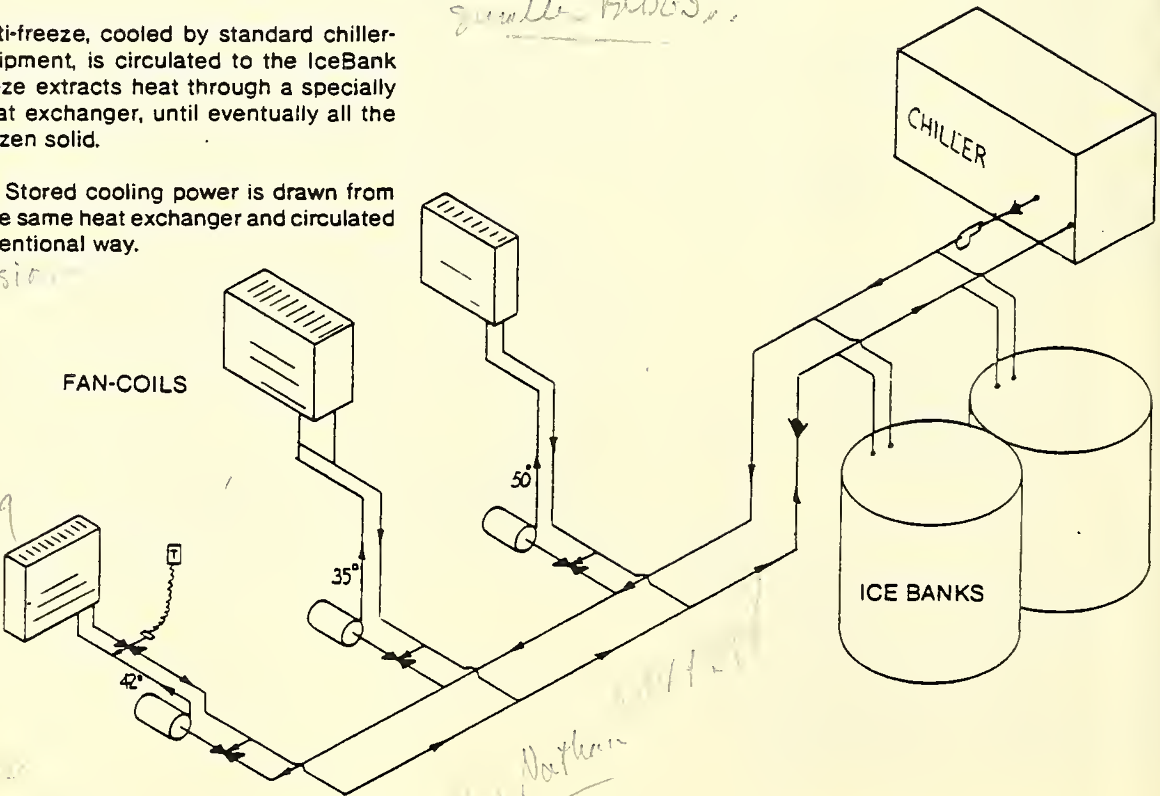
Key to economy in the air conditioning of commercial and institutional buildings

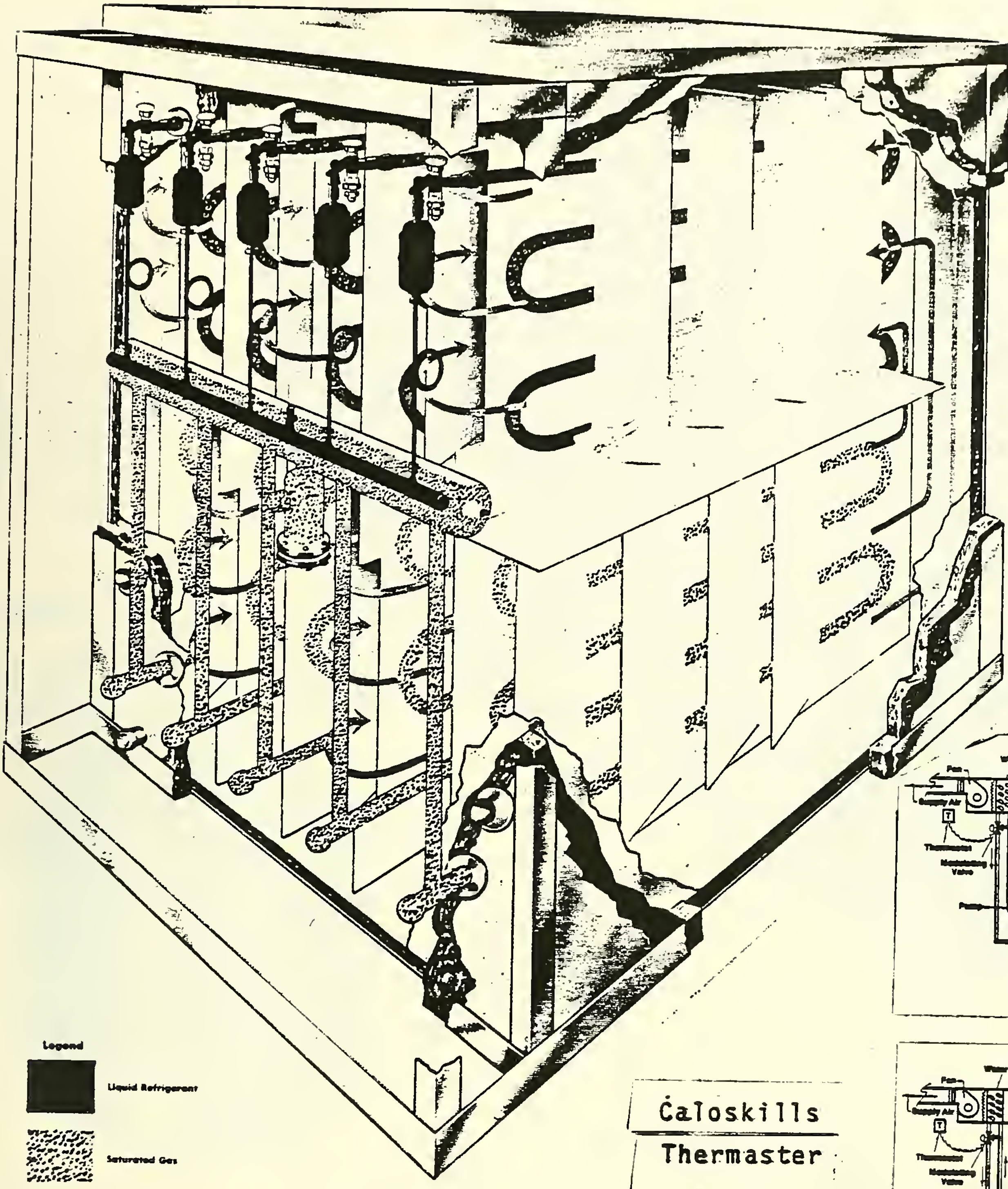
CHARGE CYCLE. Anti-freeze, cooled by standard chiller-type refrigeration equipment, is circulated to the IceBank modules. The anti-freeze extracts heat through a specially designed mat-type heat exchanger, until eventually all the water in the tank is frozen solid.

DISCHARGE CYCLE. Stored cooling power is drawn from the modules through the same heat exchanger and circulated to the load in the conventional way.

Get permission

617 878-0739





Legend

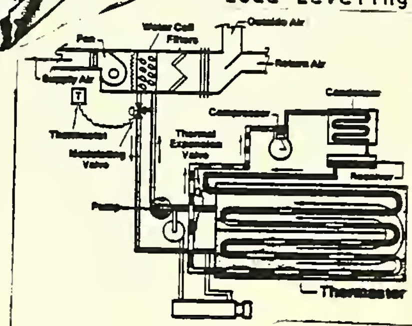
Liquid Refrigerant

Saturated Gas

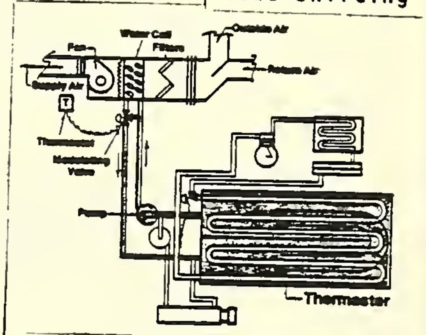
Ice

Water Flow

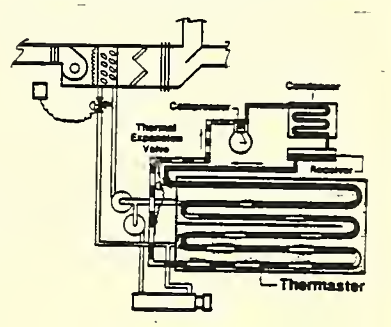
ON-PEAK
Load Leveling



ON-PEAK
Load Shifting



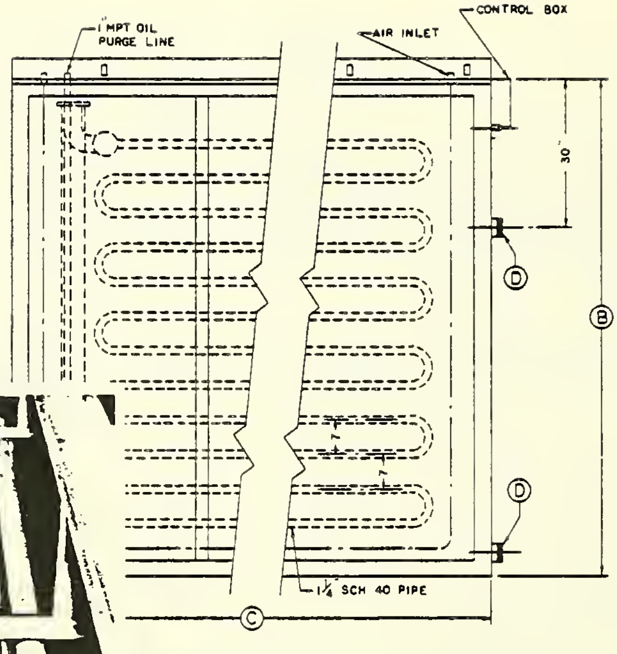
OFF-PEAK
Load Level & Load Shift



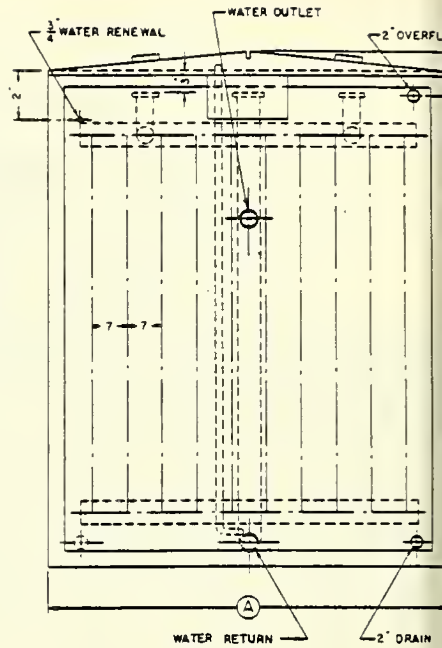
COOLING . . .

The refrigeration is turned on automatically or manually during the appropriate hours. Up to 50% of the water in the unit is turned into ice — formed in large sheets over the coils. When cooling is called for, a water circulating pump sends the chilled water to the coil in an air-handling unit and then back to the Thermaster where it is re-cooled.

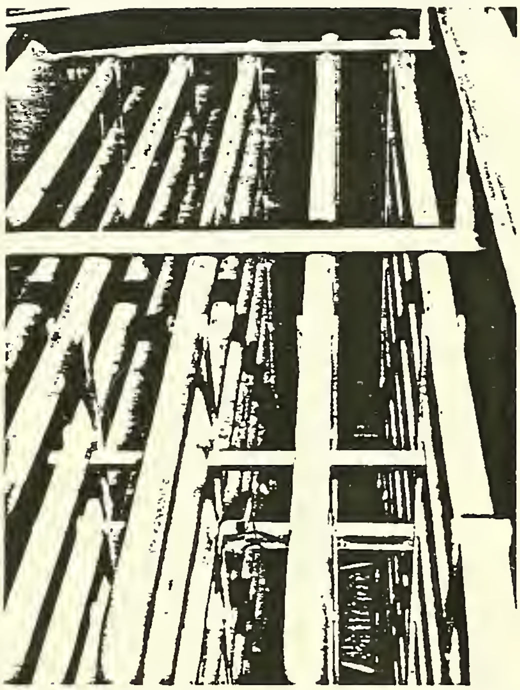
The refrigeration compressor may be off during this period, relying only on the ice for cooling. This provides for a load-shift condition. As an alternative, the refrigeration can be left on to combine the cooling effect of the ice with that of the condensing unit for increased cooling capacity and decreased equipment size. This load-leveling condition provides for greatest utilization of the cooling equipment.



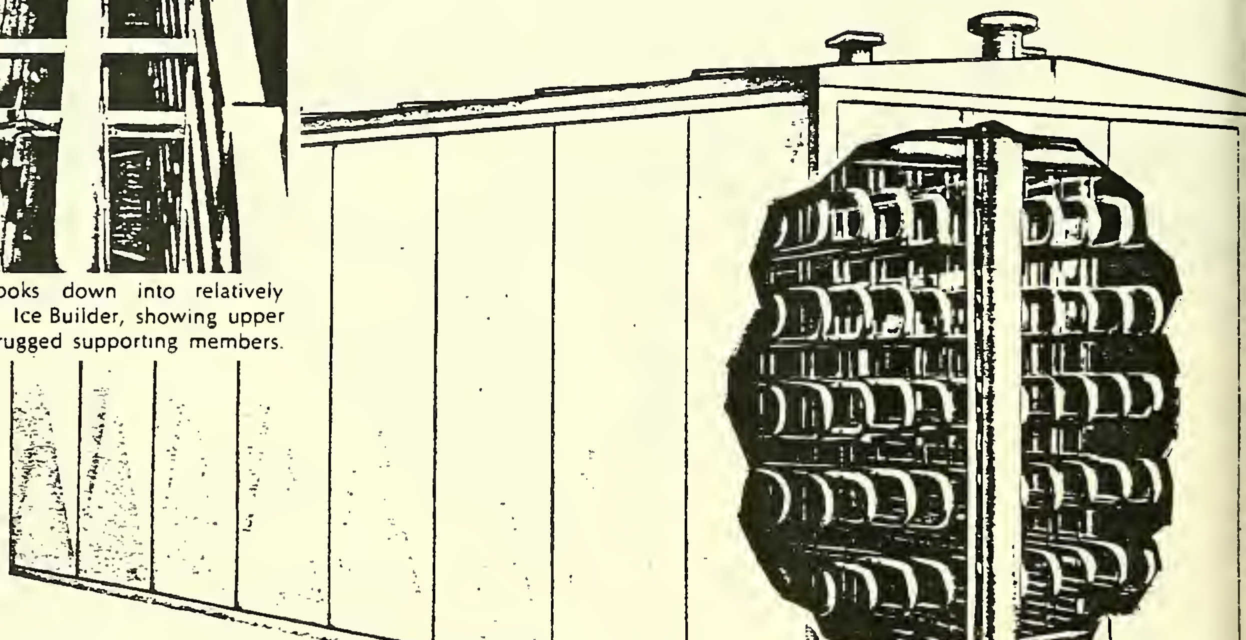
SIDE



FRONT



Illustration, above, looks down into relatively large CJ Air Agitated Ice Builder, showing upper sections of coils and rugged supporting members.



Specifications

Chester-Jensen Ice Builder

Standard Rating Data

1. All ice builders are rated at 1000 pounds of ice per ton of refrigeration with nominal 12-hour building time. This means normal freezing or evaporation rate is 12,000 BTU. per hour for 12 hours time to build each 1000 pounds of ice. Evaporation is usually at 20°F (30 psig.) Ice Builder capacity is based on 2½" ice thickness.

2. Maximum evaporation rate with agitation is approximately 200% of nominal rating. At maximum evaporation rate normal Ice Builder capacity could be realized in approximately 6 hours.

3. Maximum ice melting rate is approximately 75% full normal ice capacity in one hour.

Sample Calculations for Ice requirements Divide total Btu. cooling load per day by 144 to determine pounds of ice needed per day.

EXAMPLE: (One Day's Operation.)

Load "A" = 50,000 lbs. milk 70° – 38°
= 50,000 × .92 (specific heat of milk)
× 32° = 1,472,000 Btu.

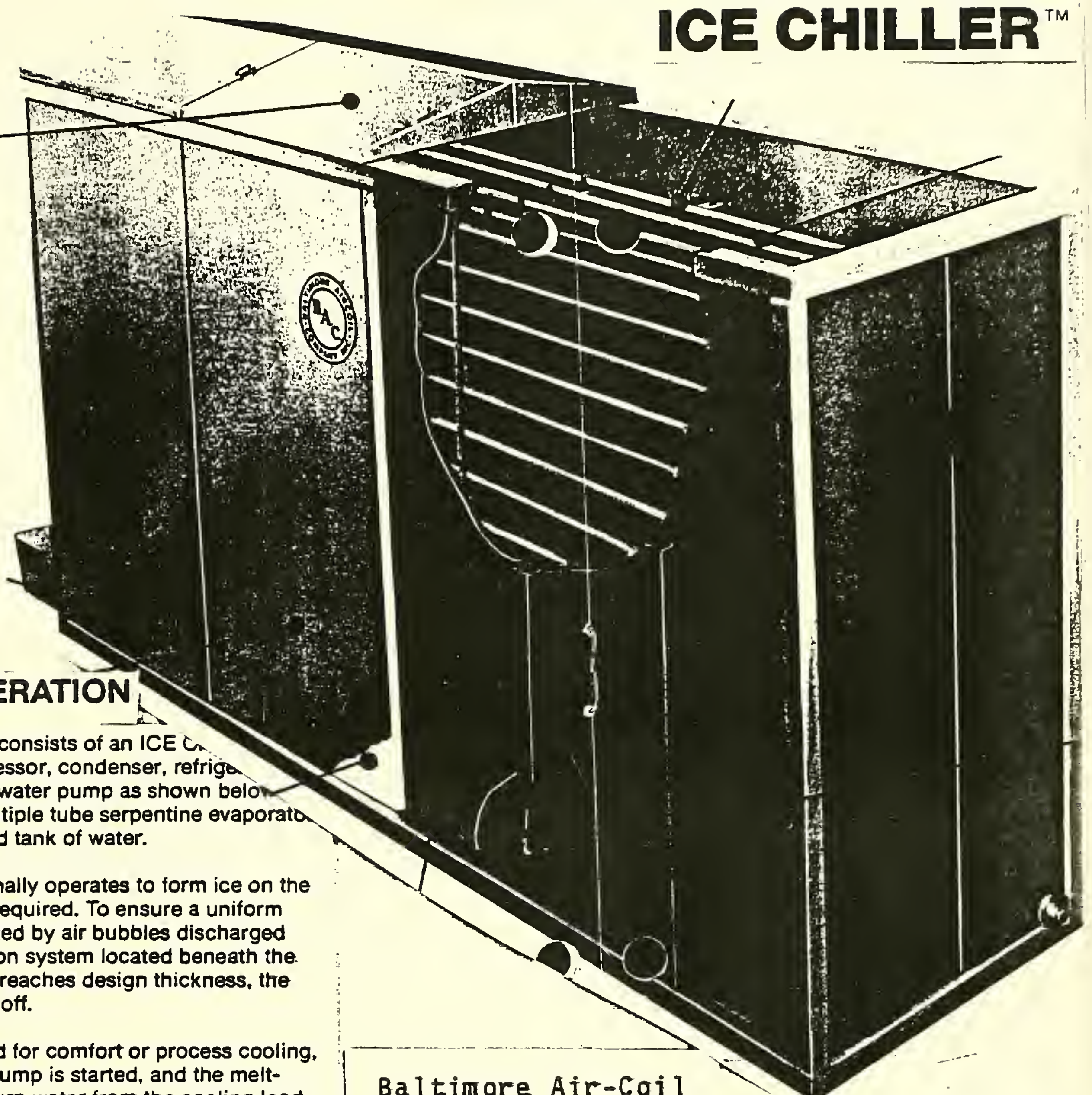
Load "B" = 5000 pounds cream 90° – 40°
= 5000 × .90 (Specific heat of cream
× 50° = 225,000 Btu

Load "C" = 8000 pounds of water 70° – 40°
= 8000 × 1.0 (Specific heat of water)
× 30° = 240,000 Btu.

Total Btu's per day = 1,937,000

$$\frac{1{,}937{,}000}{144} = 13{,}451 \text{ Pounds of Ice}$$

ICE CHILLER™



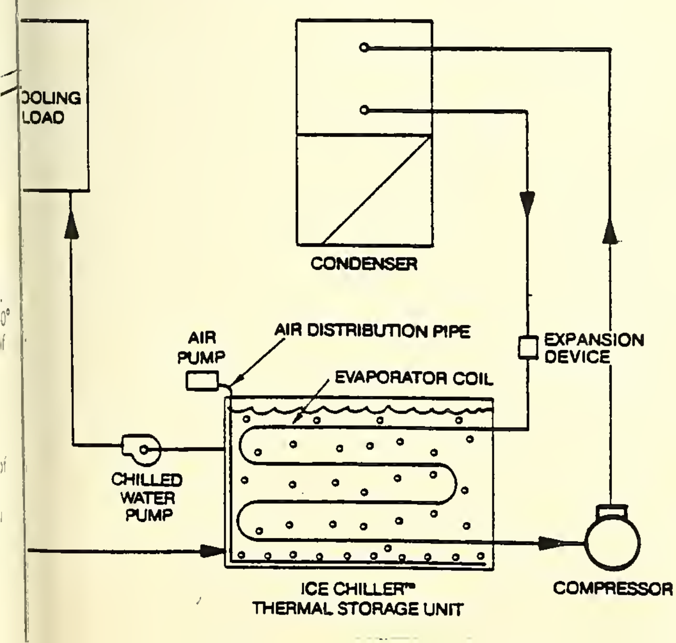
Baltimore Air-Coil

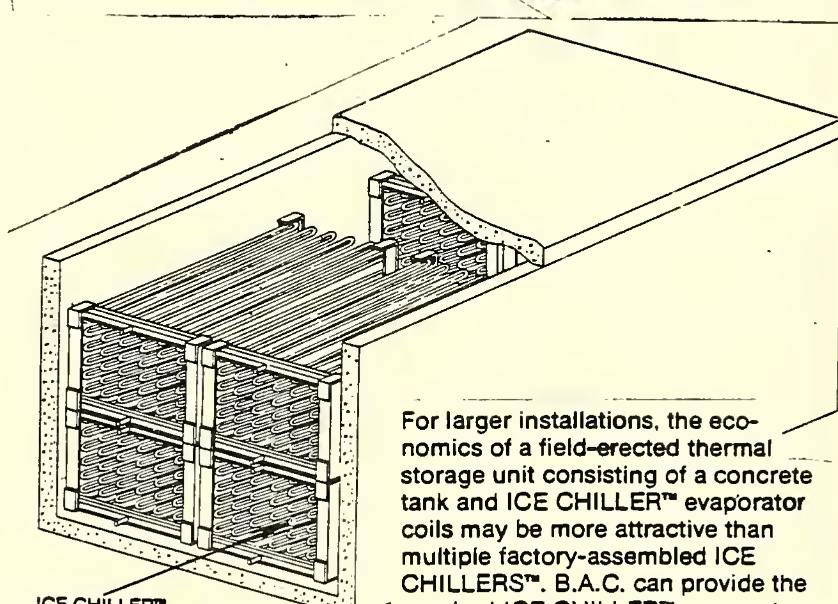
'RINCIPLE OF OPERATION

'he basic ice storage system consists of an ICE C...
'hermal Storage Unit, compressor, condenser, refrige...
xpansion device and chilled water pump as shown belo...
'he ICE CHILLER™ has a multiple tube serpentine evaporato...
oil submerged in an insulated tank of water.

'he refrigeration system normally operates to form ice on the
oil when no chilled water is required. To ensure a uniform
uild of ice, the water is agitated by air bubbles discharged
om a low pressure distribution system located beneath the
vaporator coil. When the ice reaches design thickness, the
frigeration system is turned off.

'hen chilled water is required for comfort or process cooling,
e chilled water circulating pump is started, and the melt-
own cycle begins. Warm return water from the cooling load
cooled by the melting ice. During this cycle, the tank water
agitated to provide uniform ice melting and a constant
ipply water temperature of approximately 35° F during most
the cycle.





For larger installations, the economics of a field-erected thermal storage unit consisting of a concrete tank and ICE CHILLER™ evaporator coils may be more attractive than multiple factory-assembled ICE CHILLERS™. B.A.C. can provide the required ICE CHILLER™ evaporator coils along with the necessary design and application assistance.

WATER THERMAL STORAGE IN BOSTON

SPACE HEATING RATE J

Available for space heating, water heating and air conditioning service only, where the entire heating requirements of the area served hereunder are supplied by electricity and where the heating and cooling equipment (including installation) are acceptable to the Company, and where all other service supplied to the premises is separately metered and provided under the Company's appropriate filed rate. This rate is not available for heating supplementary to that provided by other means nor for Auxiliary Service nor for temporary, periodic or seasonal service.

Rate:

Energy Charge

$16.88 for the first 200 kilowatthours or less per month.
2.31 cents per kilowatthour for the next 300 kilowatthours per month for each kilowatt of demand.
1.54 cents per kilowatthour for the excess, except that during the billing months of July through October, all use in excess of 200 kilowatthours per month shall be billed at
4.22 cents per kilowatthour.

Controlled Off-Peak Service

1.54 cents per kilowatthour for all kilowatthours for separately metered Controlled Off-Peak Service which may be supplied to thermal storage installations approved by the Company. The restricted hours of supply to such equipment shall include the hours from 10:00 A.M. to 4:00 P.M. or such other hours as the Company may specify from time to time but not exceeding six hours in any one day.

Fuel and Purchased Power Adjustment as provided in "Fuel and Purchased Power Adjustment," applicable to all kilowatthours on this rate.

Determination of Demand: The Company will install a demand meter and the maximum fifteen-minute demand (either kilowatts or at the option of the Company 80 percent of the kilovolt amperes), as shown by such meter each month, but not less than 5 kilowatts, will be used in computing the monthly bill.

Primary Metering Credit: Where only alternating current service is supplied a credit of two percent of the total bill not including the Fuel Adjustment and other Miscellaneous Charges and before deduction of the Transformer Ownership Allowance, will be made when energy is metered at the nominal voltage of 2400 volts or higher.

Minimum Charge: $16.88 per month.

(Continued)

Four buildings in Boston planned for water thermal storage; two are in the process of operation while the other two have the massive storage tanks in place but are on a hold to output them with the necessary hardware and controls. The transportation building was the pioneer in Boston; it's 870K HVAC needs are assisted by the three 250-gallon water storage tanks in the basement. During the severe winter months the three tanks transfer excess heat from lights and people to the building's hearing needs; while during the summer they pre-cool the return water to 43° or store chilled water for the day, enabling the three ________ chillers to take advantage of the off-peak rates.

Exchange place which has the same amount of water storage (750K gal.) but a larger floor area, 1,040K compared to 870K , is assisted during the very cold season by a heat pump of 400-ton capacity. As it cools the interior of the building it shifts the heat to the facade or down to the storage tanks for later use. In summer the water tanks lower the return water from 60° to 54° while the two 700-ton electrical lentrifigal chillers then lower the 54° water to 44°. The fourteen separate tanks with their sophisticated controls enable the system to contain varying amounts of hot and cold water simultaneously while overcoming the blending problem; together with the variable speed pumps and heat exchangers they shave 800 tons from the 2,200 ton cooling load.

The office component of the old Federal Reserve Development is a 39-story structure of 750K; while the 300-room hotel occupies the 9 floors of the recycled reserve building.

A variable volume system services the office perimeter via 4-pipe fancoil units while a constant volume system cools the interior. The cooling tower provides extra capacity for special tenant cooling requirements.

The refrigeration machines include two chillers at 600 tons and one at 400 tons for the office and two at 300 tons for the hotel together with individual systems for the function and public spaces. As the office tower rests on 4'-wide by 9'-deep grade beams four 60K gallon concrete water tanks were place between these. Currently these are used for heat storage and eventually will be hooked up to the chillers to enable them to take advantage of the off-peak rates. As this storage unit has only 24K gallons, it would warrant an investigation into an ice system thereby increasing the real capacity by four times.

The 40-story Dewey Square tower installed the largest volume of water storage capacity; 1 million gallons for nearly one million square feet. However, the problem of the east side interceptor delay, necessitated their being temporarily used as sewage holding tanks.

POST OFFICE SQUARE

JUNG BRANNEN, ARCHS.
J.R. LORING & ASSOCS, ENGINEERS

FICE TOWER -
41 STORIES ; 760 K SQ.FT. CONDITIONED SPACE

Refrigeration machines in basement generate chilled water
2 UNITS @ 600 T
1 UNIT @ 400 T
2 Story mechanical room for every 3^{rd} floor

Four pipe fan coil units located in perimeter offices
(chilled or hot water)
Constant volume system - Interior zone (every 3 floors)

Cooling tower includes extra capacity for special tenant cooling requirements; condenser water outlets for tenant equip on every 3^{rd} floor.
Fresh air intake every 3^{rd} floor

(computers, telephone switches, & electrical rooms)

TEL MERIDIAN

2 chillers in basement @ 300 T & pumps

2 pipe fan coils & electric heat in guest rooms

Cooling tower in garage

Numerous (seven) variable volumn systems for function & commercial space.

June 3, 1982

ONE POST OFFICE SQUARE

Hot Water Storage System

Summary Information

I. Installed Equipment

A. Storage tanks: 4 @ 60,000 gal each, 3 of which are full at any given time. Total Capacity: 3 X 60,000 gal = 180,000 gal.

B. Heat Exchangers HE-1A & HE-1B: See JRLA Drawing M-23.

II. To Be Installed: Pumps, piping, controls

III. System Operation

System Water (Tube Side) Flow Rate: 665 GPM
Tank Water (Shell Side) Flow Rate: 600 GPM

A. Charging Tanks (Heat Gain to Tanks: 6,000 MBH)

	Entering HE	Leaving HE	ΔT
System Water	108.0° F	90.0° F	-18.0° F
Tank Water	104.9° F	85.1° F	+19.8° F

B. Discharging Tanks (Heat Gain to System: 4,800 MBH)

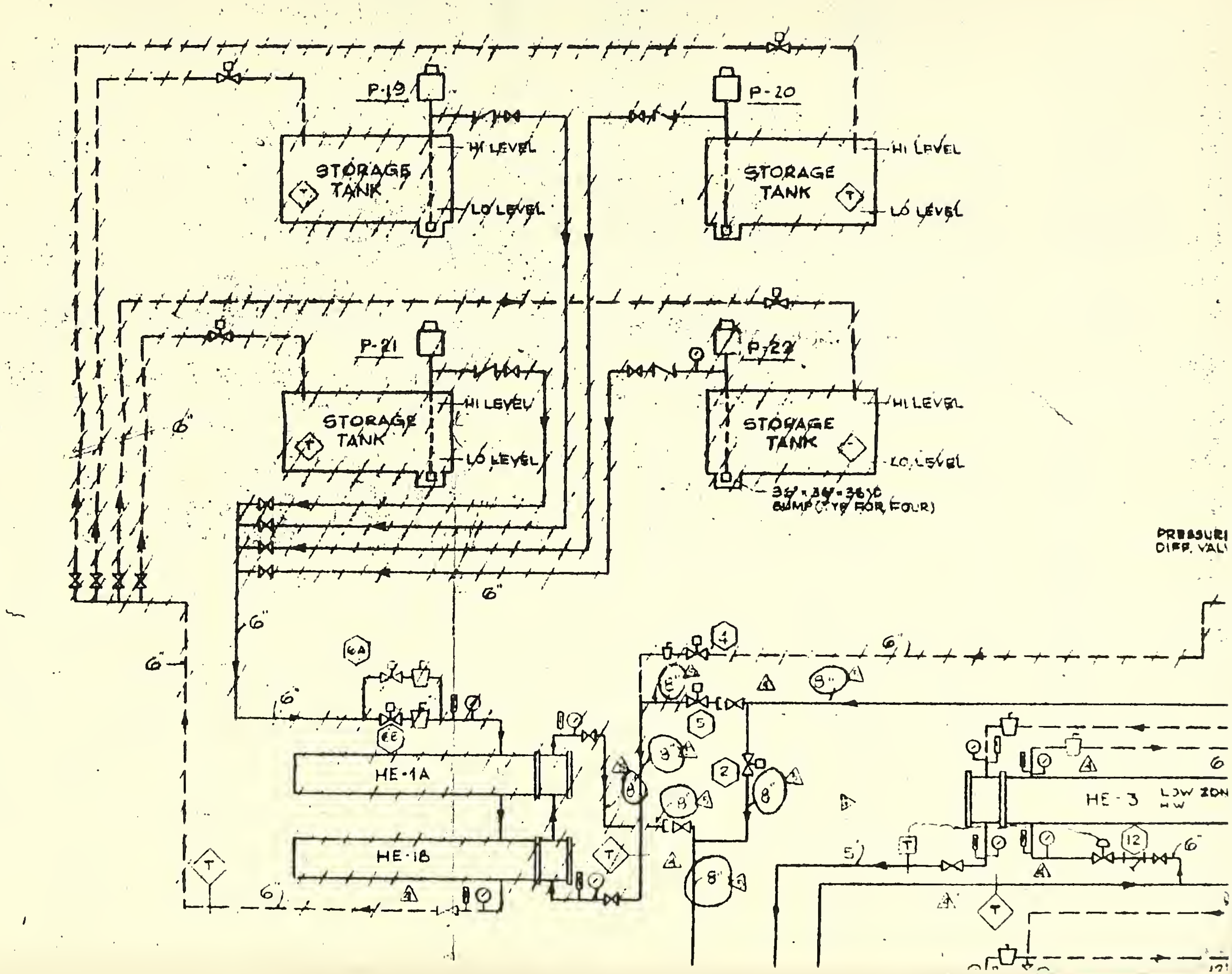
	Entering HE	Leaving HE	ΔT
System Water	85.0° F	99.4° F	+14.4° F
Tank Water	103.0° F	87.4° F	-15.6° F

IV. Heating System Characteristics

A. Peak Heating Demand: 10,500 MBH

B. Boiler Capacity: 2 each at 7,000 MBH

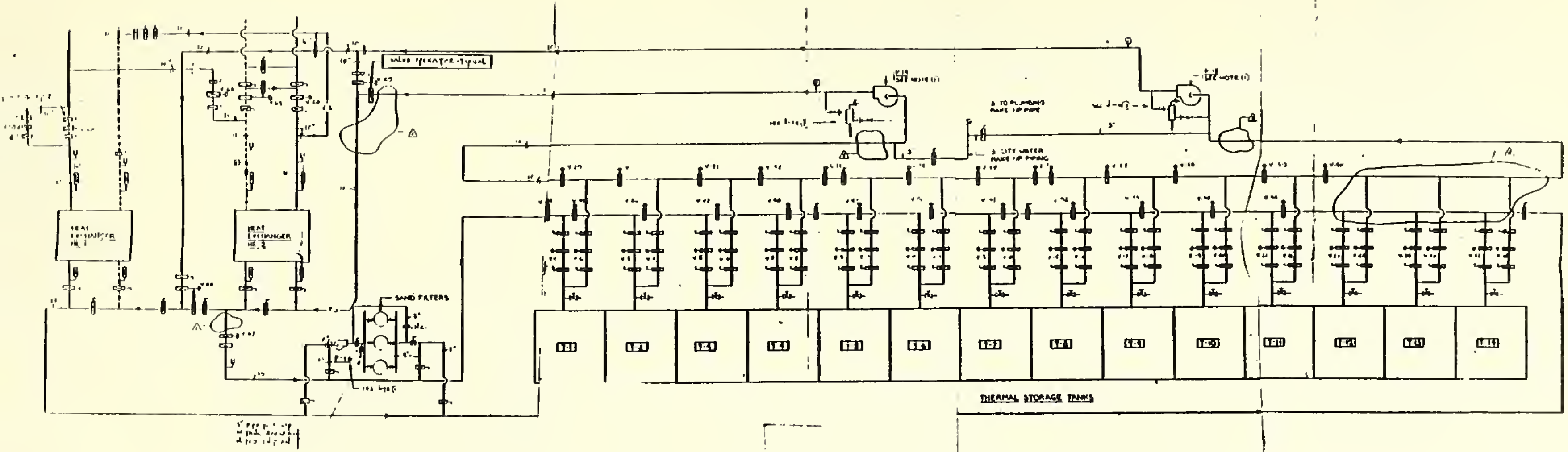
C. Heat Recovery Chiller (RM-3): 15° ΔT X 665 GPM X 500 ≈ 5,000 MBH


P-19
P-20
P-21
P-22
STORAGE TANK
STORAGE TANK
STORAGE TANK
STORAGE TANK
HI LEVEL
LO LEVEL
HI LEVEL
LO LEVEL
HI LEVEL
LO LEVEL
HI LEVEL
LO LEVEL
SUMP (TYP FOR FOUR)
PRESSURE DIFF. VAL
HE-1A
HE-1B
HE-3
LOW ZON HW
6"
6A
6E
4
5
2
12
5"
8"

EXCHANGE PLACE

SCORZIELLO ASSOCS. - 357-6060 - RICHARD NOCE

HOT WATER 3600 KW ELECTRIC BOILER - FinTube @ FACADE
3 ELECTRIC CENTRIFUGAL CHILLERS
2 @ 700 T ; 1 heat pump chiller @ 400 T
750 K gal. THERMAL STORAGE TANKS
installed mainly for off peak cooling ; also used for heating season
SPECIAL J=DEMAND RATE FOR STORAGE FROM BOSTON EDISON
14 TANKS - HOT & COLD @ SAME TIME
STORAGE CAPACITY OF 800 T chiller run for 8 HOURS.
TANKS PROVIDE 800 T of 2200 T TOTAL LOAD
TANKS LOWER WATER FROM 60° → 54° } 16° T Differentia
2 CHILLERS LOWER WATER FROM 54° - 44° }
VARIABLE SPEED PUMPS & FLAT PLATE HEAT EXCHANGERS in TANKS
FRESH AIR INTAKES - EVERY FLOOR ; OUTDOOR AIR UNIT
BELOW 58° - (SPRING & FALL) COOL FROM COOLING TOWERS WITH
FLAT PLATE HEAT EXCHANGERS (in lieu of strainer system)
HEAT PUMP - USED in WINTER TO COOL INTERIOR SPACE
EXTRA HEAT SENT TO FACADE ;
EXCESS HEAT ↑ - SENT TO THERMAL TANKS.
MITCHELL PARTNERSHIP - TNT Limited of Toronto & Calgary
are studying possibility of switching to ice.
Right now - too much power to manufacture ice.



WZMH Habib Inc.
Architects & Planners

Sears Crescent Building
Boston, Massachusetts
02108

Scorziello Associates, Inc.
HVAC Engineers

216 Tremont Street
Boston, Massachusetts
02118

53 STATE STREET OFFICE BUILDING ADDITIONS AND ALTERATIONS

Olympia & York
State Street Company

SCALE NOT TO SCALE

DRAWING TITLE
FLOW SCHEMATIC DIAGRAM

DRAWING NUMBER
59-865

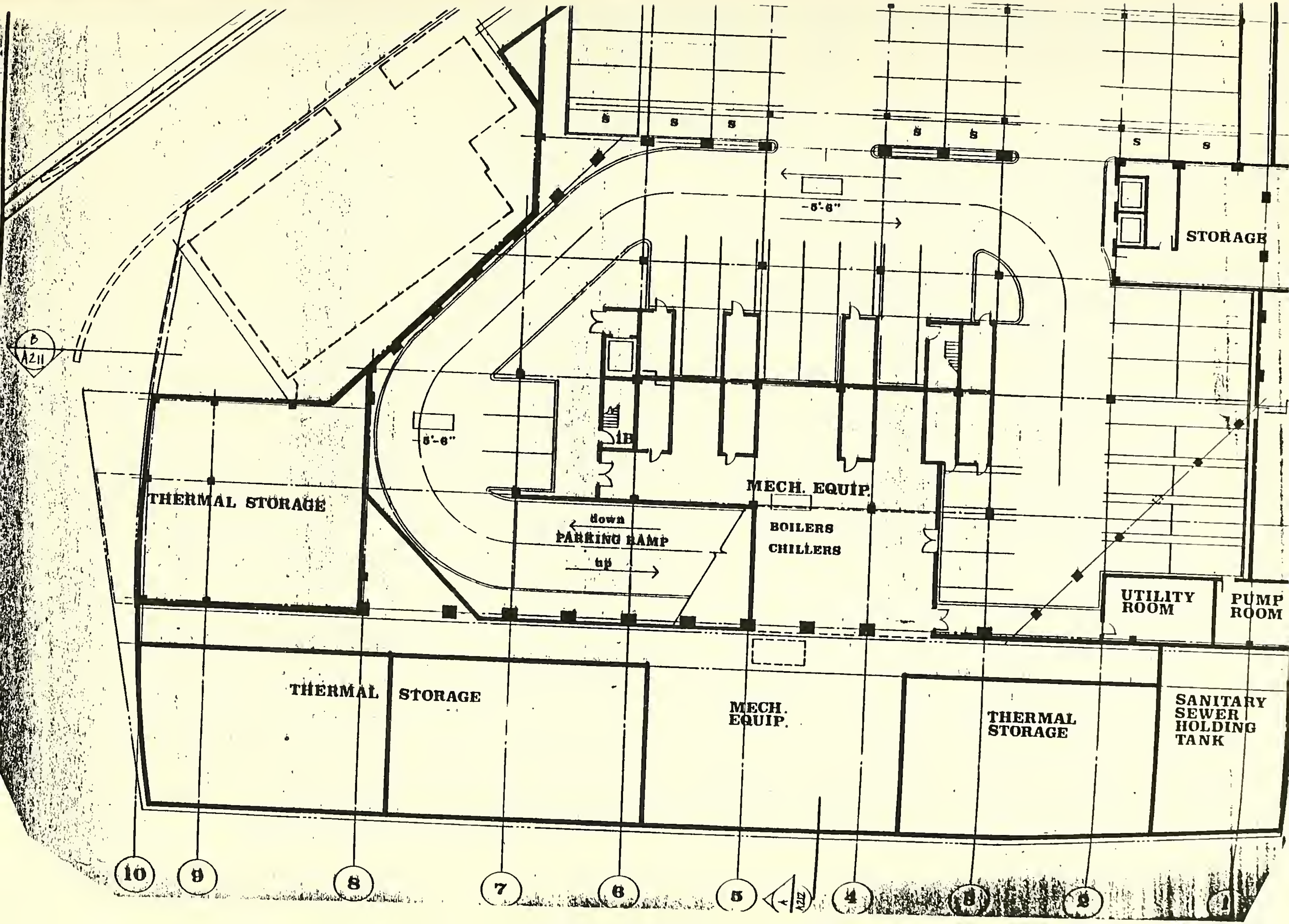
DEWEY SQUARE TOWER

THREE ELECTRICAL CENTRIFIGAL REFRIGERATION MACHINES UTILIZE 2250 kwh & SUPPLY 3K TONS COOLING.

The HVAC system will consist of local air handling units serving either one, two or three floors with an energy saving variable air volume (VAV) system. For further energy conservation, the VAV system will utilize ceiling induction air terminal units that will utilize the heat accumulated in the return air plenum ceilings for perimeter heating.

The HVAC system, due to its localized VAV characteristics, will have a quasi-linear relationship between the building cooling demand and the fan and refrigeration energies required. Thus, if the building is one-half full, approximately one-half the amount of energy will be required for cooling than if the building were full. In addition, a double-bundle heat recovery feature will be incorporated into one of the refrigeration units. This energy saving feature will return warm air to the building for perimeter heating during winter when there is demand for heat. During warm periods when no heating is required, excess heat will be expelled. Furthermore, a strainer cycle will be utilized to substitute condenser water for chilled water during cold periods when outside temperatures are such that sufficient cooled water can be obtained from the cooling tower without the use of compressors.

To permit off-hour usage of electrical energy for both cooling and heating, a water storage tank containing approximately 1,000,000 gallons will be provided. Water in the tank will be cooled at night, during Boston Edison's off-peak hours. The cooled water will be used the following day for air conditioning purposes. Thus the building will not add to peak-hour loading on Boston Edison's existing electrical generating facilities. This will mitigate energy usage impacts since the building will demand energy when sufficient supply exists during the night, rather than further tax the peak hour supplies. Future need for additional electrical generating facilities may be reduced by this measure.



STORAGE
S
S
S
S
S
S
S
-5'-6"
-5'-6"
THERMAL STORAGE
down
PARKING RAMP
up
MECH. EQUIP.
BOILERS
CHILLERS
UTILITY ROOM
PUMP ROOM
THERMAL STORAGE
MECH. EQUIP.
THERMAL STORAGE
SANITARY SEWER HOLDING TANK
A211
A212
10
9
8
7
6
5
4
3
2
1

A CONCEPT

At this point, SEA took the energy reins and evaluated over 20 different central and de-centralized heating, ventilating and air conditioning systems. From this study, the four best air systems were programmed with a common cooling source utilizing Trane Company's TRACE Program for a life cycle energy simulation. After this initial computer run, four alternate cooling source systems with the most economical air system from Run #1 were simulated in the same manner. The bottom line of these computer runs suggested centralized variable air volume systems with terminal low temperature booster coils, central heat recovery dual condenser chillers (heat pumps) and water storage.

SYSTEM STORAGE

As the above concept was being finalized for schematic presentation to the Bureau of Building Construction, SEA, in its review of the computer output, became aware of what they believed to be a deficiency in the computer life cycle energy simulation. The "deficiency" turned out to be a computer program limitation. The program read-out indicated that during the heating month of January, the facility mechanical system required supplementary heat, yet it also used the cooling tower for heat rejection. SEA restudied the computer program and, with the help of Trane Company personnel, determined that the program limited 50 gallons of water storage for each ton of air conditioning. With this 50 gallon limit removed, SEA made another life cycle system simulation. That run demonstrated, beyond a doubt, that there was no need for supplementary heat and that the facility could be totally heated from the heat gains generated from within and excess heat gains properly stored for later use.

It was with this final run that SEA was confronted with the greatest challenge in the Company's twenty year existence. GC&A and SEA recommended to the BBC that the new Transportation Building be served by the variable air volume central air systems with terminal heating coils served by central heat pumps and backed-up by three 250,000-gallon underground hot water storage tanks which could be utilized as a heat source for the building <u>without any back-up supplementary heating media</u>! In addition, the tanks would also serve to store chilled water for summer peak air conditioning load shaving by utilizing smaller than peak load air conditioning refrigeration units and run these chillers continuously through the night. The nighttime cycle could also take advantage of "off-peak" electric rates for economical operation as well. (Figure 5)

Now came the challenge! No engineering firm in Boston, including SEA, had ever designed a heating, ventilating and air conditioning system with water storage without back-up heat source such as utility steam or a fossil fuel boiler. GC&A/SEA were convinced that the structure was thermally efficient and the concept could be achieved. They felt justified in advising against the added cost and operating maintenance that an idle back-up heating system would create.

<u>WHEN</u>: In summer months, as shown in the Tank Time of Year Schedule, all three tanks are charged with 43°F water from off-peak electric hours operation, as specified previously. This next sequence provides pre-cooling of chilled water return CHWR-1 by utilizing stored chilled water which results in less electricity consumed by chillers RU-1 and RU-2 at higher daytime electric rate.

<u>HOW</u>: The central air system modulates chilled water coil control valves toward full flow position due to maximum space cooling need.

PEAK CHILLED WATER MODE was considered when maximum cooling capacity was required during the occupied cycle. (Figure 12)

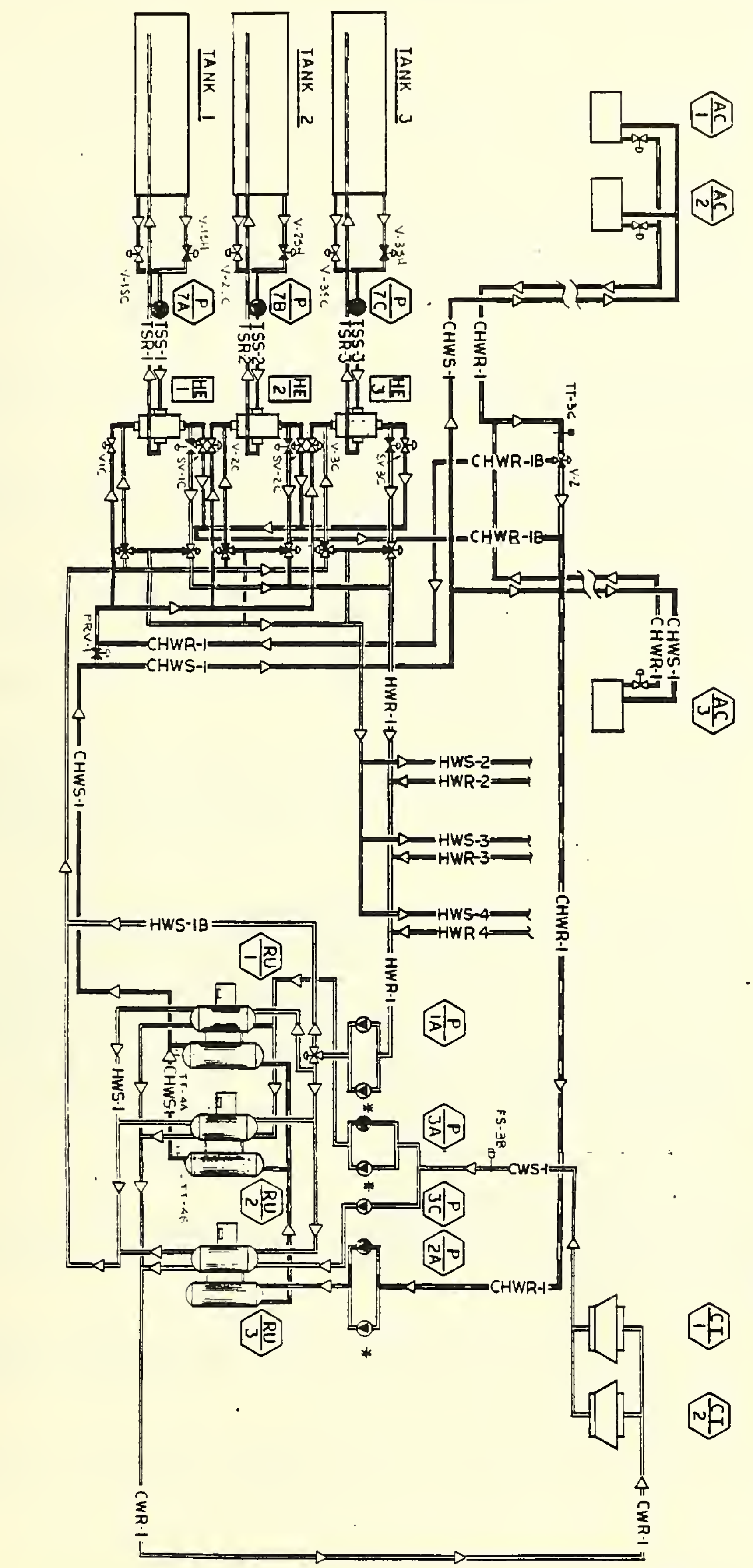


FIGURE 12

DRAWING:

SEQUENCE TITLE:

FOR ASSOCIATED DISCRIPTION SEE SHEETS

SHEET 7 OF 11

PROJECT PW74-1
CONTRACT NO. 1

TRANSPORTATION BUILDING
PARK PLAZA, BOSTON, MASS.

GOODY, CLANCY & ASSOCIATES, INC.– ARCHITECTS
334 BOYLSTON STREET, BOSTON, MASSACHUSETTS

TRANS BLDG

Heat exchanger HE-1 is also in chilled water flow mode through its valves V-1C and SV-1C.

Tank No. 1 recirculating pump P-7A is operating, tank high level valve V-1SH remains in its normally-open position and tank low level valve V-1SC remains in its normally-closed position to allow circulation from the top of the tank. Tank No. 2 and Tank No. 3 operate in a similar fashion.

Chilled water coil control valves in the central air systems are closed (if their associated fans are off).

Chilled water supply CHWS-1 charges the three heat exchangers, after which chilled water return CHWR-1B flows back to the three chillers through CHWR-1 and pump P-2A.

The condenser water temperature transmitter TT-3B cycles the cooling tower CT-1 and CT-2 fans as specified previously.

OFF-PEAK STORAGE MODE was examined when the air conditioning is off and the building is in its unoccupied cycle. (Figure 11)

WHEN: In the months of June, July and August, as shown in Tank Time of Year Schedule, chilled water at 43°F is stored in all three tanks. The charging of the tanks with chilled water occurs during off-peak electric rate hours.

HOW: The time program activated this control sequence by automatically starting chilled water CHWR-1 pump P-2A (or standby pump P-2S) and condenser water CWS-1 pump P-3C. Chilled water flows through parallel-connected chillers RU-1 and RU-2 from in-series chiller RU-3. When the chillers are operating, RU-3 chilled water discharge temperature maintains 48°F by its discharge temperature transmitter TT-4C. Chilled water then flows through chillers parallel-connected RU-1 and RU-2 and is cooled to 40°F via their discharge temperature transmitters TT-4A and TT-4B.

Since the cooling coil valves of central air systems are in their normally-closed positions due to unoccupied cycle, pressure differential valve PRV-1 is in its full open position for flow of chilled water supply CHWS-1 to all three heat exchangers.

Circulating pump P-7A, P-7B and P-7C at the three tanks operate together with their respective high level valves V-1SH, V-2SH and V-3SH open and low level valves V-1SC, V-2SC and V-3SC closed.

Heat exchanger HE-1, HE-2 and HE-3 are cooled by CHWS-1 flow via opening valves V-1C and SV-1C for HE-1, V-2C and SV-2C for HE-2 and V-3C and SV-3C for HE-3.

All of the chilled water leaving the three heat exchangers returns through chilled water return CHWR-1B and then into the CHWR-1 system. Chilled water return CHWR-1 3-way valve V-2 is closed to CHWR-1B.

ANNUAL
STORAGE

ANNUAL ICE STORAGE

NATURAL SNOW

MANCHESTER, N.H. - UNDER PKING LOT

OTTAWA, Canada - to QUARRY

ice

FROM PONDS & RIVERS TO ICE HOUSE

MECHANICAL - BY PRODUCT OF HEATING SYSTEM

ACES - OAK RIDGE, TENN, - HEAT PUMP

ICES - Integrated Community Energy System

MECHANICAL/ WINTER

DIRECT CONTACT

SNOW BOXES

BLOW COLD WINTER AIR ON WATER SPRAY

BOXES WITH VENTED SIDES - Canada

PLYWOOD PLATE SYSTEM - Kansas.

ICE PYRAMIDS in SKYSCRAPER WAREHSE - Canada

PRINCETONS SNOW GUN

BLIGHTS NICE/AC III - Minnesota

Northbys Ice Machine - Rhode Island

INDIRECT CONTACT

GORSKIS FINNED HEAT PIPES - ARGONNE

YUANS WICKED HEAT PIPES - UNIV. OF WASH.

REFRIGERANT THRU Coils @ PURDUE

REFRIGERANT THRU Coils - BLIGH @ MINNESOTA

Various types of refrigerants can be sent through a coil submerged in a volume of water, transforming it into a block of ice as done at Purdue and University of Minnesota or variations of heat pipes can transfer the winters cold from the air to a volume of water. Gorski used finned heat pipes at Argonne (to allow the ice to break off and float to the surface) while Yuan at the University of Washington utilized an innovative wicked heat pipe. Direct contact systems are variations on the regular ski slope snow gun or the army ice island platforms. Kirkpatricks snow gun at the Prudential office in Princeton builds a 1000 ton ice mound under a quilt while a multitude of snow box variations exist; boxes with vented sides; plywood plate systems and ice pyramids in skyscraper warehouses. Northby proposes direct contact manufacture in Rhode Island utilizing a large surface area while Thomas Bligh at Minnesota pumped water from the bottom of the tank to the ice surface creating a large block by winter's end.

Storage can take place in an insulated warehouse; todays foams can provide an extremely high R value, Insulation material can merely be thrown on a mound of ice; pits and underground tanks can take advantage of the earths insulation. Because of the enormous volumes necessary to last a year, Mr. Northbys floating cylinders hold the most promise for coastal urban centers. Much investigation into floating platforms, barges, and warehouses has been done in relation to the oil industry and a variation or adaptation of these might well answer the space premium of our denser cities. As far as heat transfer is concerned, the best method would depend on the water supply, the amount of impurities in the water and the capacity of the city's sewerage system.

Although packaged and custom built ice thermal storage systems for daily peak energy load leveling are quite common, there are only a scattering of annual systems in place now; the main reason being the high volume of storage required. However, these units will provide real energy savings rather than just shifting and leveling the peak loads.

The ice could be natural, a mechanical by product of the heating process, or a semi-mechanical product utilizing the renewable cold of winter. Storage can take place in a variation of the old fashioned ice house or ice pit, and heat transfer done by sending ice melt to the building, warm condenser water to the ice pile or via a heat exchanger of the melt and condenser water.

The natural ice source of the 19th century was provided by the many lakes and ponds. While today it is the high volume of snow which must be removed from urban streets and parking lots anyway.

Two projects have been implemented which obtain free cooling as a by product of the heating process in the winter via an ice maker heat pump. Single homes in Oak Ridge utilize this method together with a vocational education school in Reedsburg, Wisconsin.

The ice manufacturing process can be achieved through either direct or indirect contact to the cold. Variations on the various forms of ice machinery of old composed of metal flat plates, belts, or cylinders operate directly in the winter air or by sending the cooled refrigeration behind the metal.

Snow Box

Project Ice Box stores winter cold by freezing water into a large above ground hollow box with open venetian-blind walls. The lower slits that compose the walls are sloped with their lower edges towards the inside. During winter, water is sprayed into the structure so that ice is formed by the naturally low temperatures and wind factors. As the ice increases in thickness, it freezes onto the louvers, sealing the edges of the box. Further addition of water causes freezing to proceed upwards. The thickness of the block of ice produced is dependent upon the weather and the size of the structure In the summer the box is enclosed with insulated panels to inhibit natural melting so that controlled melting can be used for cooling.

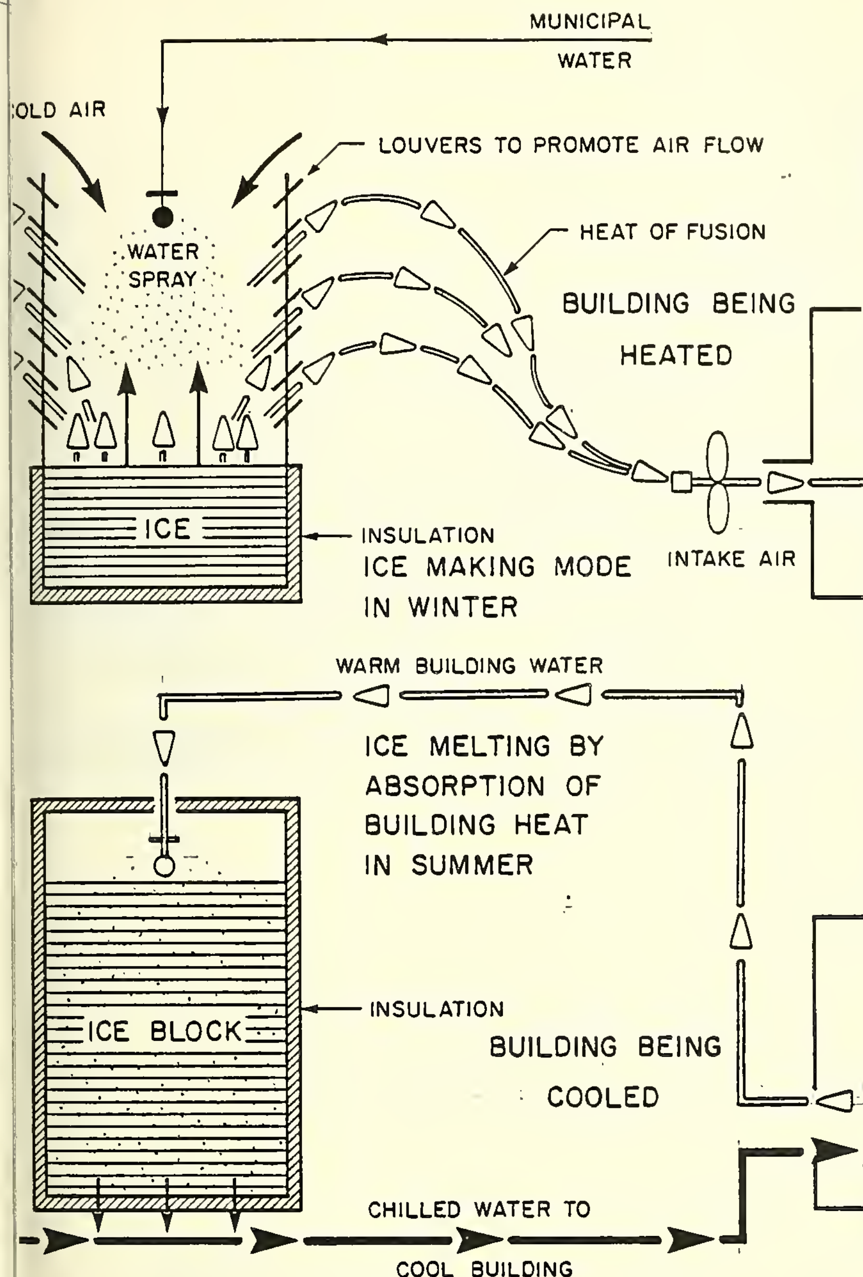
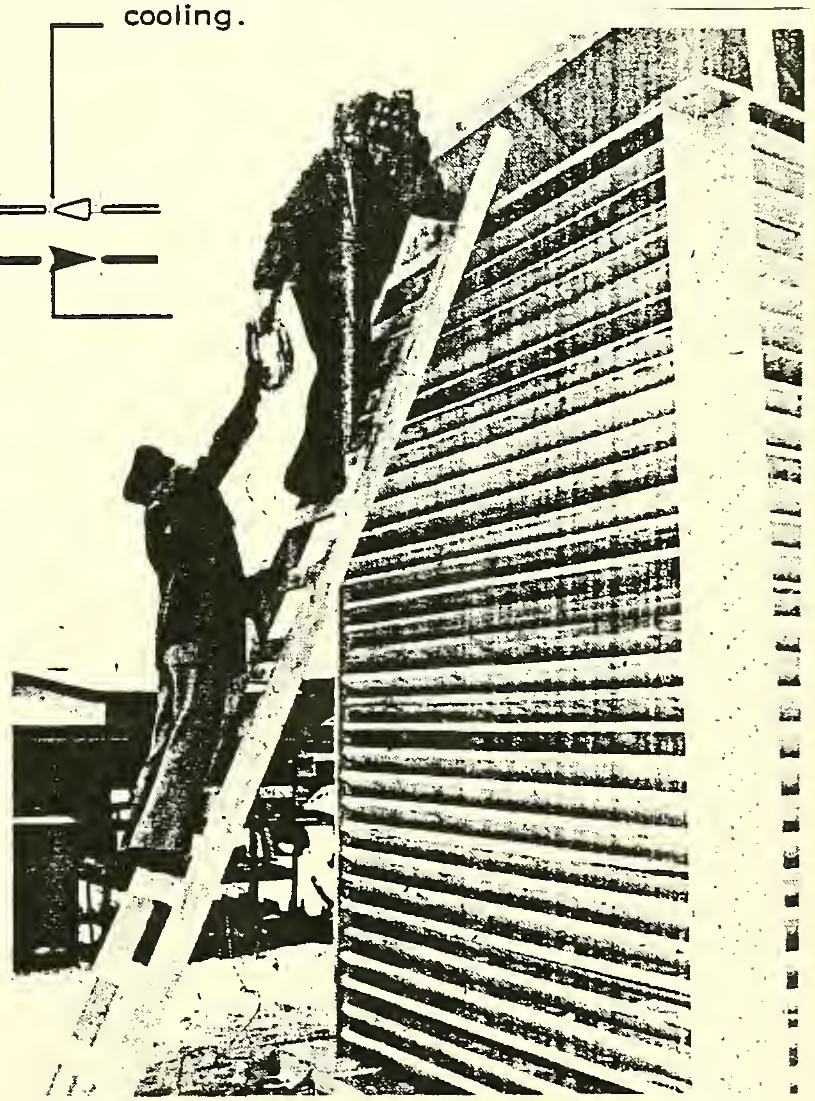


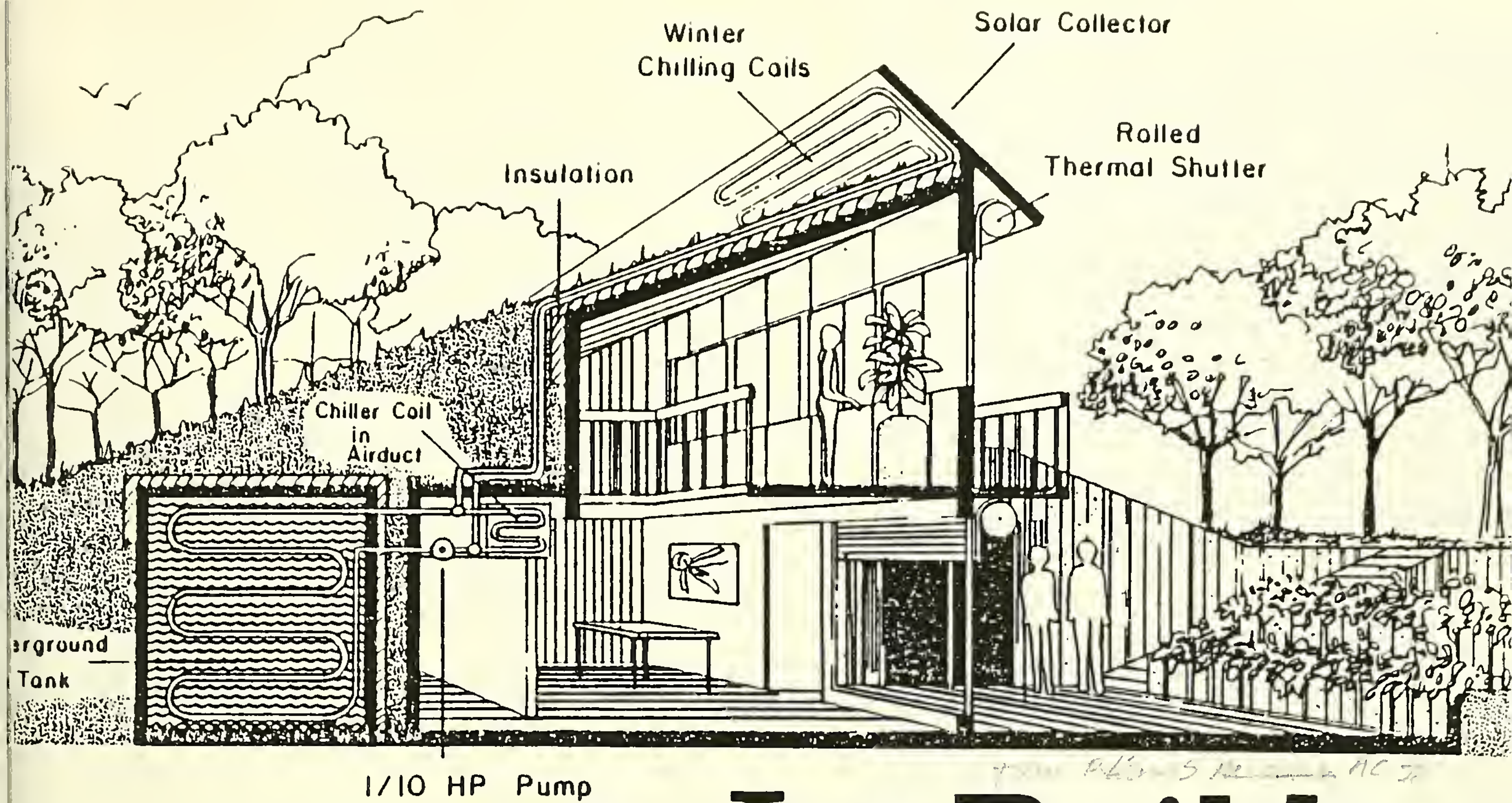
Figure I. ANNUAL OPERATING CYCLE OF ICEBOX

Public Works Canada's first box was 8' x 8' x 12' high and fabricated from wood and panels of polystyrene, progressively affixed to the outside of the box whenever the ice thickness approached the panel width. For an average 8700° heating day winter for Ottawa they calculated that a block of ice over 31' high should be attainable.

In melting tests 60° water was poured into the top of the Block and drained through a vertical central hole leaving the block at 36° G. This melt rate provided 10 tons, much higher than the minimum one ton required.



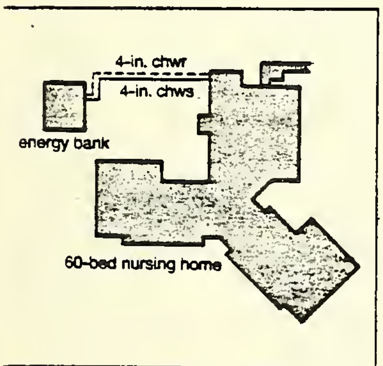
The block of ice inside this structure may be the future of air conditioning.



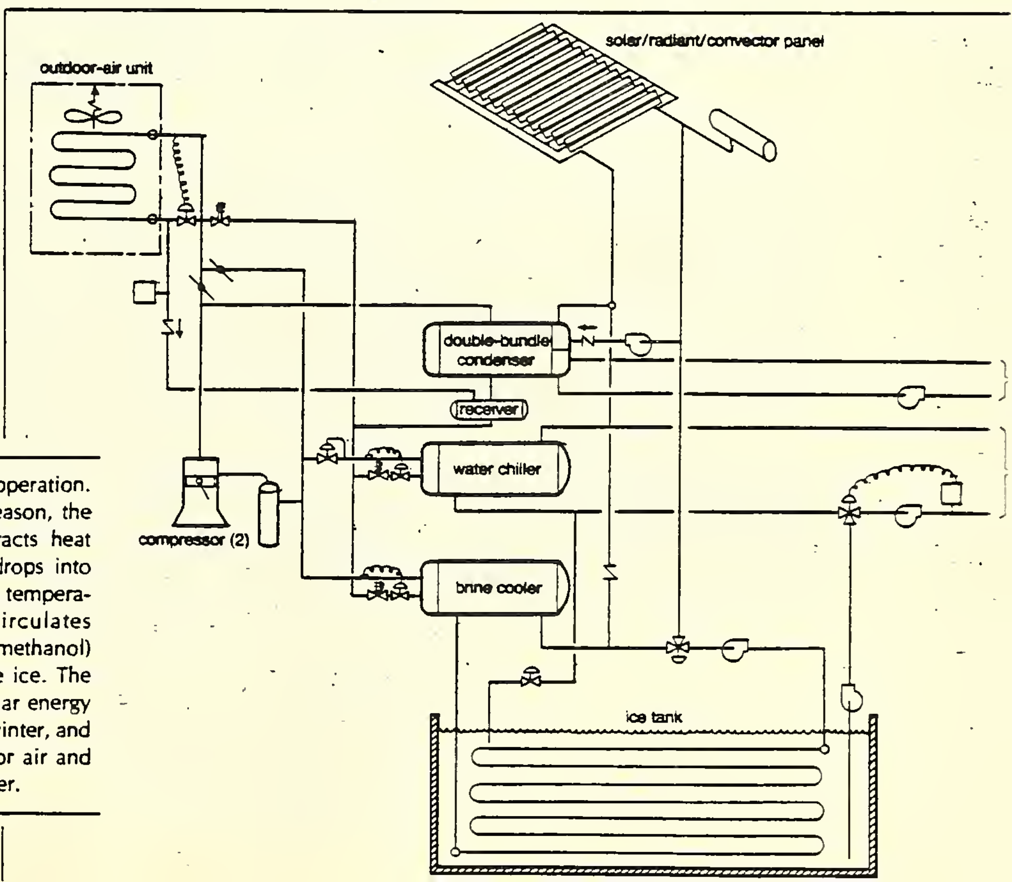
Ice Builder

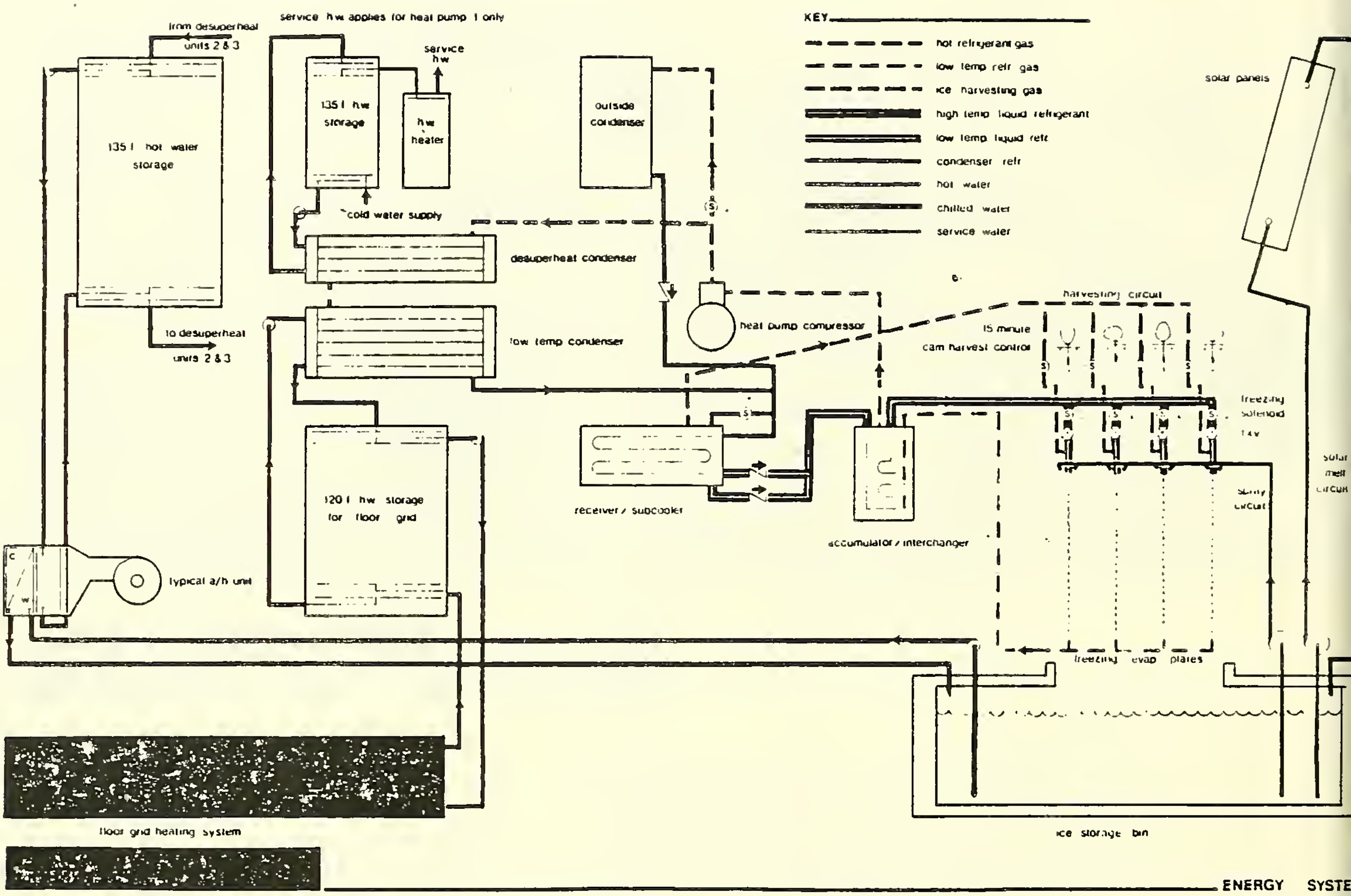
In Wilmington Delaware, a heat pump and storage bin provide 75 tons of cooling and 800K BTU of heating for the 60 bed VA Nursing Home. By making ice in winter and summer nights the electric demand is greatly reduced. A computer monitor governed by weather and season chooses from eight modes of operation.

Antifreeze circulates from the winter chilling coils to the coils in the underground tank. The resulting ice is stored until summer. When air conditioning is required, cold antifreeze is circulated through the chiller coil which cools and dehumidifies the air in the ventilation air duct. The only energy required is the 1/10 HP circulation pump.



Because the 60-bed VA nursing home in Wilmington had been designed before VA engineers decided to use the Annual Cycle Energy System, consulting engineer Robert Werden put his "energy bank" in a separate structure. It incorporates refrigeration (heat pump) equipment, a 40- by 50- by 10-ft ice tank, a solar/radiant/convector panel, and a computer system to monitor and control the operation. During the heating season, the outdoor air unit extracts heat from the air until it drops into the 40's. At lower air temperatures, refrigerant circulates through the brine (methanol) cooler so it can make ice. The roof panel absorbs solar energy to melt excess ice in winter, and rejects heat to outdoor air and the night sky in summer.





ENERGY SYSTE

Ice Maker

The 17,000 sq.ft. Reedsburg Center Vocational School in Wisconsin uses an ice maker heat pump system to store hot water which is extracted from a two stage condenser. The desuperheat condenser supplies domestic hot water the tank at 49° and the second stage condenser stores energy in tanks at 40° for heating. Water is cooled and frozen on thin vertical evaporator plates; ice is removed by a defrost cycle and drops into concrete storage bins. The high pressure gas from the receiver/subcover is valved into the low pressure refrigerant evaporator plates to harvest the ice every 15 minutes.

As heating needs exceed cooling requirements, the ice is melted by circulating water from the ice bin through low temperature solar collectors or using cooling coils in the air handlers if some cooling is needed in winter. In late March the solar melting is turned off to provide ice for summer cooling. The total building energy usage is averaging 36,000 Btu/sq.ft./year.

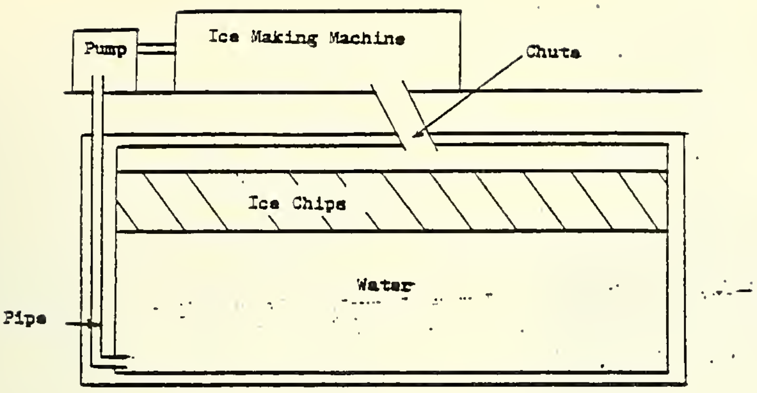


Figure 2: Ice Making Machine and Tank (Bligh, 1978)

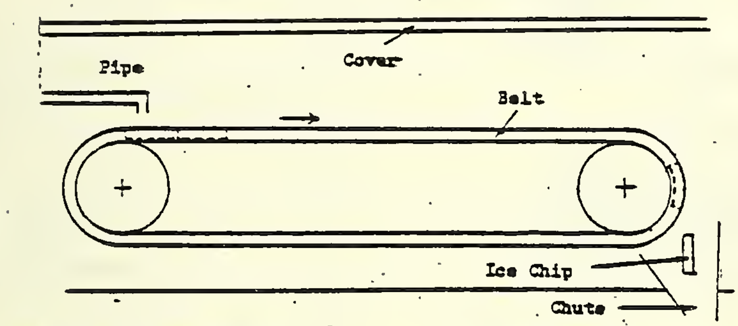
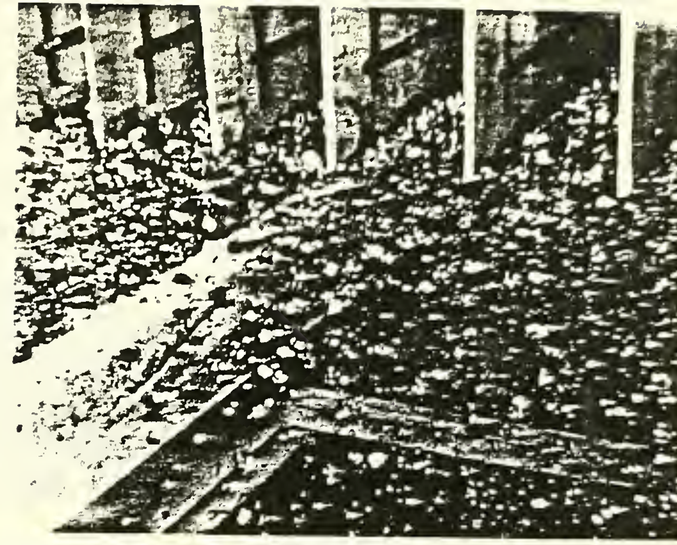
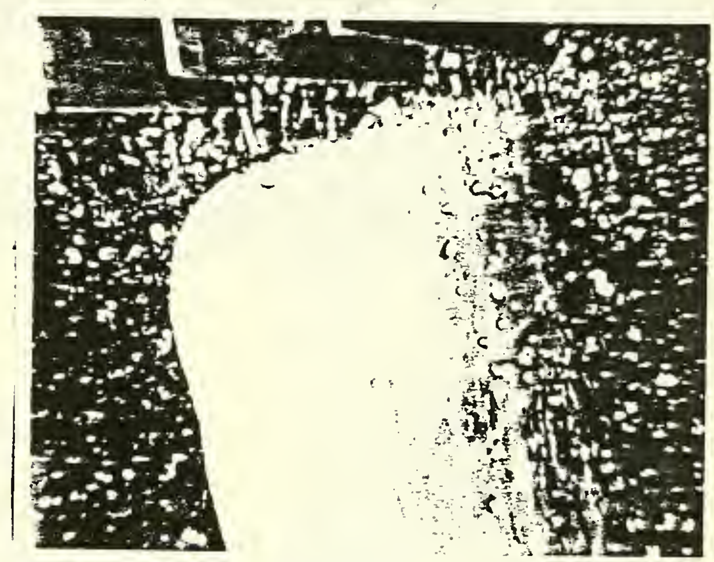


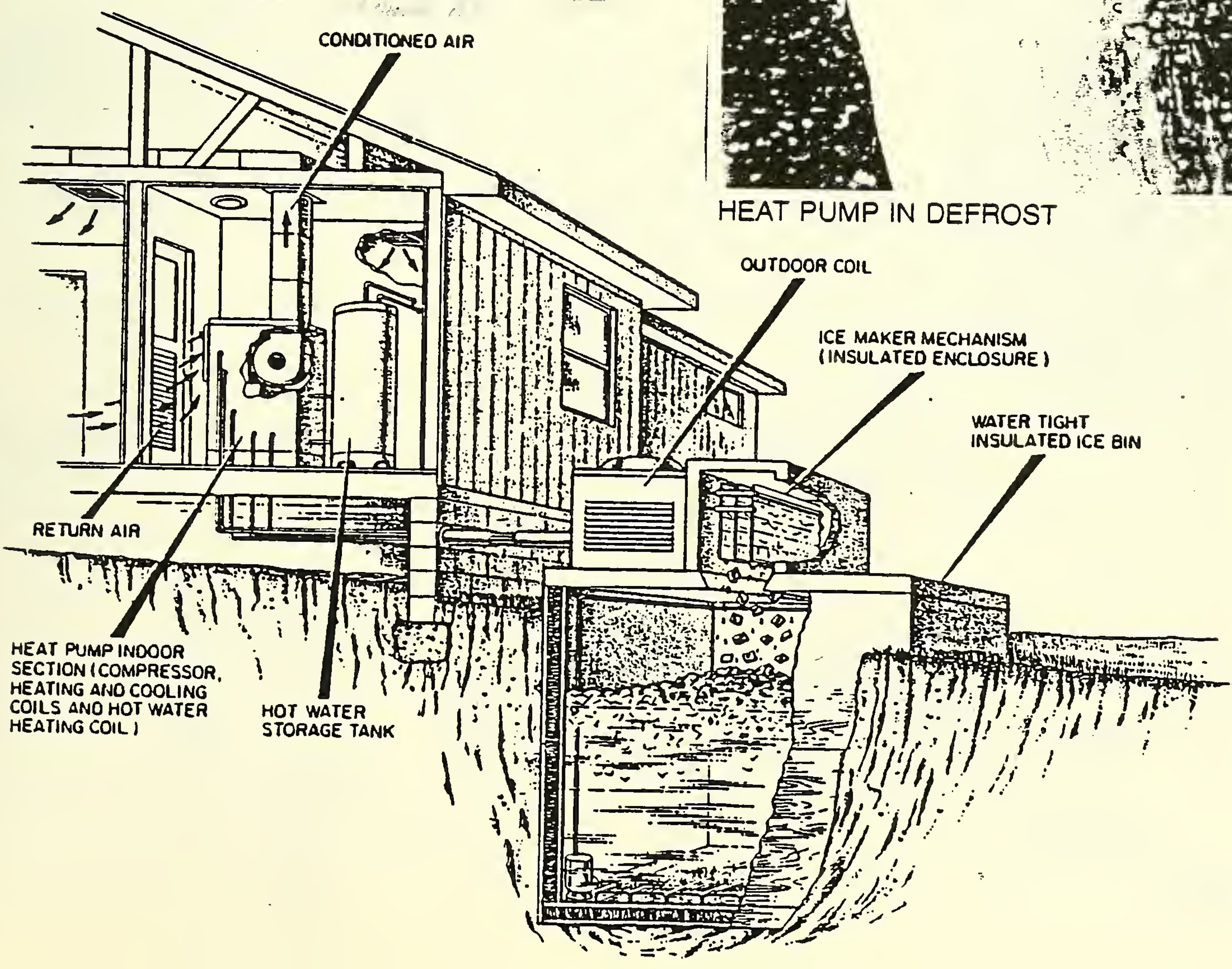
Figure 3: Ice Making Machine (Bligh, 1978)



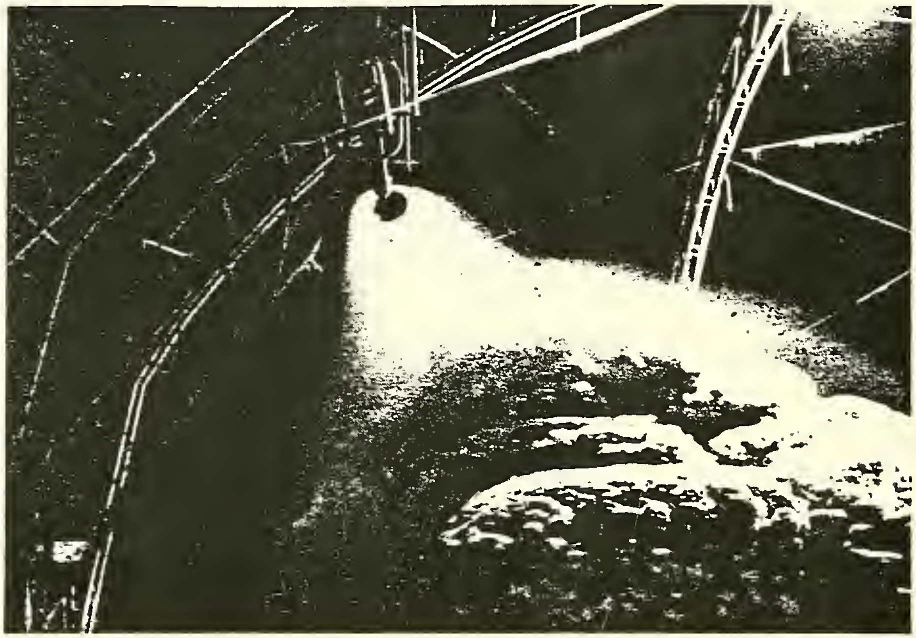
HEAT PUMP IN OPERATION



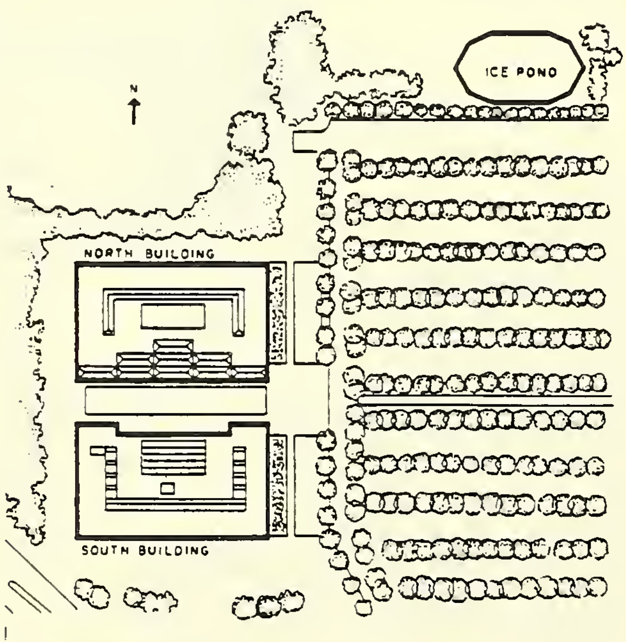
HEAT PUMP IN DEFROST

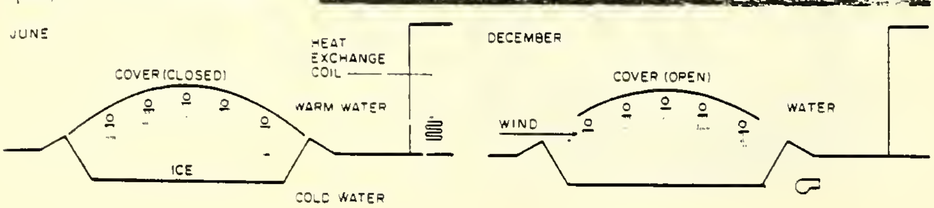


Water atomizers work in conjunction with snow making machines to provide enough ice for summer cooling in the Princeton project. As the photo shows, the ice pit is covered with a heavy canvas dome which reduces melting by sun and wind. The ice is formed naturally during the winter months, then in the summer when it begins to melt, the cold ice water is drained off by a pump and piped into the building to be cooled. There, the water passes through water-to-air heat exchangers.



The two buildings of Enerplex are sited so that they clearly relate to each other, with facing atriums and interior plans based on a U-shaped double-loaded corridor, topped by skylights, that acts as a light-slot to permit daylight into inner offices. The ice pond (below) will be used initially for the North Building only. When temperatures fall below freezing in December, the cover of the pond is opened and water is atomized in the air. Snow is formed, which compacts into ice. Water that has not frozen is recirculated until the structure is completly full of ice. When full, the cover is closed and the ice is stored for summer use. When cooling is required, "melt water" is drawn from the bottom of the pond, passed through a heat-exchange coil where it absorbs heat from the building, and is then returned to the pond where it is sprayed over the ice mass.



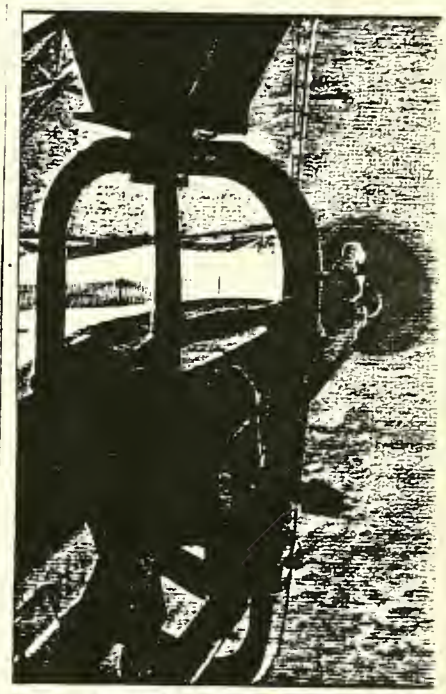


Now a team of scientists at Princeton University has devised a plan to air-condition a building with something resembling sherbet. They intend to use a snow maker to build a 5,000-ton mountain of slush in winter; then, as it slowly melts in summer, they will pipe the cool water through the air-conditioning system. Their "ice pond"—the seasonal opposite of solar ponds that heat buildings with hot water collected during summer months—may sound like a fancy reincarnation of the old ice house, but it has a definite contemporary appeal. In large structures, it might cut the cost of electricity required for cooling by 90 per cent. "By saving winter cold until summer," says Princeton physicist Theodore Taylor, the ice pond lets man "roll with nature instead of fighting it."

Princeton's ice pond sounded feasible enough to get a commercial tryout next year. The Prudential Insurance Co. is constructing a $20 million office complex in nearby Plainsboro, N.J., and is counting on a half-acre ice pond to keep it cool during summers to come. The company has already bankrolled $400,000 worth of ice pond studies by Princeton (the government wasn't interested in funding the project), and if Taylor's calculations are right, it has found a bargain. The system uses most of its electricity—to power the snow maker—in the winter, when rates are low, and at today's utility rates, it will save $12,000 a year in electricity costs. The ice pile works best if it's paired with an energy-thrifty building, such as Prudential's, which has good insulation and "light slots" to channel in sunshine and reduce the need for bulbs. But even a ramshackle storage shack used to test the first ice pond two years ago showed that the system can cool the air during long hot summers.

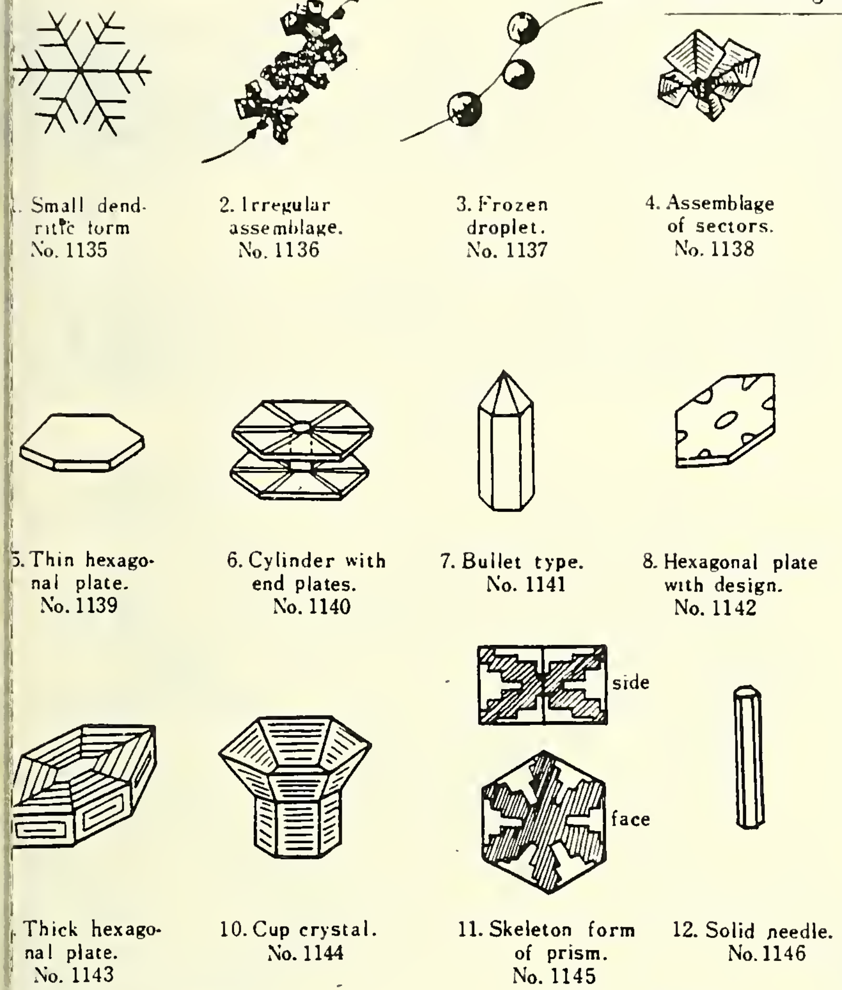
The first thing an ice pond needs is ice—the sort produced by snow-making machines when nature fails to deliver on the ski slopes. Taylor's machine supplies about 11 tons an hour on a cold winter day; 100 tons, which would cost $35 to make, could air-condition virtually any house for a summer. For the Prudential project, the machine will pile the ice into a 20-foot-deep pit lined with insulating vinyl. Once the ice is stockpiled, a layer of insulation on top controls melting. The 1979 pond was covered with straw and vinyl weighted down with old tires, but last winter's prototype was crowned more elegantly, with quilted urethane foam. Both last year's prototype and the Prudential model have a blinding-white vinyl dome that protects the ice from wind and rain and bright of day. The insulation isn't quite perfect, but it isn't meant to be: in the summer the ice must slowly melt. The trickle of water, just a little warmer than 32 degrees Fahrenheit, is pumped from the bottom of the ice mound through the building's heat exchanger (chart), where it cools air flowing through ducts. Then the water, which warms up during its circuit, returns to the ice and percolates down, melting more ice during its descent.

The experimental ice ponds near the Princeton campus, used for summer air conditioning, were in various stages of testing last winter: one with its black vinyl lining ready to be filled, another covered by a 32-foot Dacron dome that shades an ice mountain grown from the slushy spray of snow-making equipment.

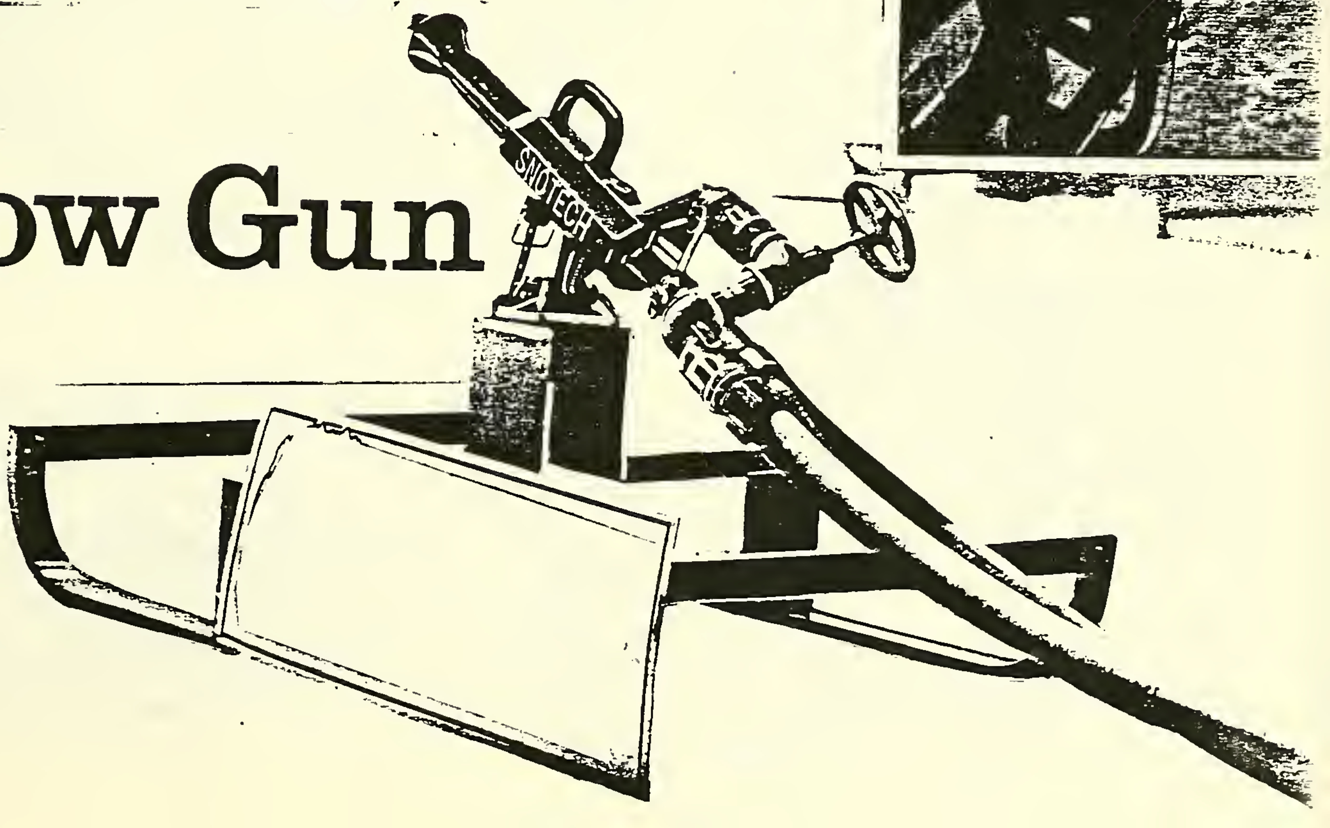


ARTIFICIAL SNOW

Schematic diagrams of initial stage.



Snow Gun



Heat pump's ice storage cuts heating/cooling costs

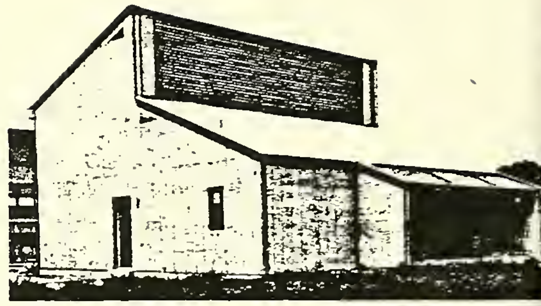
A new strategy for reducing energy costs in the heating and cooling of residential, institutional and commercial buildings that has recently emerged from ERDA's Oak Ridge National Laboratory utilizes ice-making to get Btu's for heating in the winter and "free" cooling in the summer. The approach, called Annual Cycle Energy System (ACES), takes advantage of the physical fact that 144 Btu's of heat must be extracted from a pound of 32 F water to convert it to ice, and the same amount of heat must be applied to melt the ice. A crude parallel is old-timers' use of winter-frozen ice to preserve fresh foods in the summer.

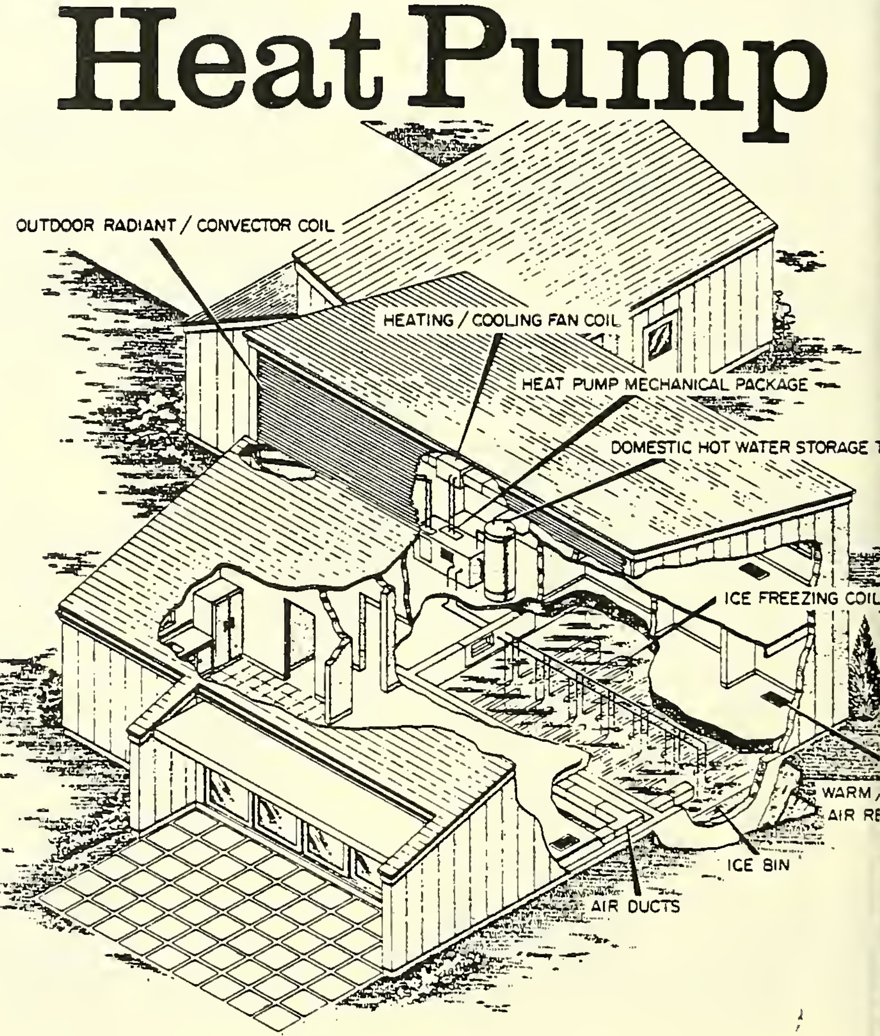
At the heart of the system is a heat pump that extracts heat from the outdoor air during the heating season until the air's temperature drops to around 40 F. When the outdoor air is colder than this it "frosts up" the outdoor coils of the heat pump with a resulting drop in the efficiency. But what if the heat pump were to make ice in a large tank when outdoor air temperatures are at freezing or below? Not only would the efficiency of the heating cycle be improved, but the ice could be built up in the tank to be melted in warm weather.

This basic idea of making ice to heat a house was suggested by engineers over 40 years ago. Credit for reviving it belongs to engineer Harry C. Fischer who, as a heat-pump engineer in the '50s, tried to interest the industry in a heat pump that made ice for heating and kept the ice accumulated for space cooling. As Fischer notes, the idea didn't "fly" because of the cost of storage for the ice and the low cost of energy. But eight months after the Arab oil embargo, Harry Fischer, then in retirement, presented his ice-storage idea to the Energy Division at Oak Ridge National Laboratory (ORNL), which had been looking for conservation approaches for building thermal envelopes, water heaters and heat pumps. ORNL, operated by Union Carbide Corporation, liked the idea and hired him as a staff consultant to pursue development. In December 1974 HUD awarded Fischer's group a $100,000 grant for the ACES project, and by February, the first test ACES system was built and operating. A month later Westinghouse Electric Corporation, which had been urged by Fischer to build an ACES system, had one installed in their domestic engineering center near Pittsburgh. Now an ACES demonstration residence (shown right) has been built in Knoxville, Tennessee as one of several houses in the Tennessee Energy Conservation in Housing program sponsored by ORNL, the University of Tennessee, and the Tennessee Valley Authority.

Cost of an ACES system for an 1800-sq-ft house has been estimated to be $5,000-6,000 for Washington, D.C. and Philadelphia, compared with $1500 for electric heating and air conditioning.

This ACES (Annual Cycle Energy System) house at the University of Tennessee will have its operation compared with a solar house and a conventional house. The system comprises a heat pump on the second level behind the outdoor radiant/convector coil and a 16- by 21- by 8-ft ice bin. System makes ice in winter to get heat and melts it in the summer to get cooling. To make more ice in summer, refrigerant is rejected to the outdoor coil.



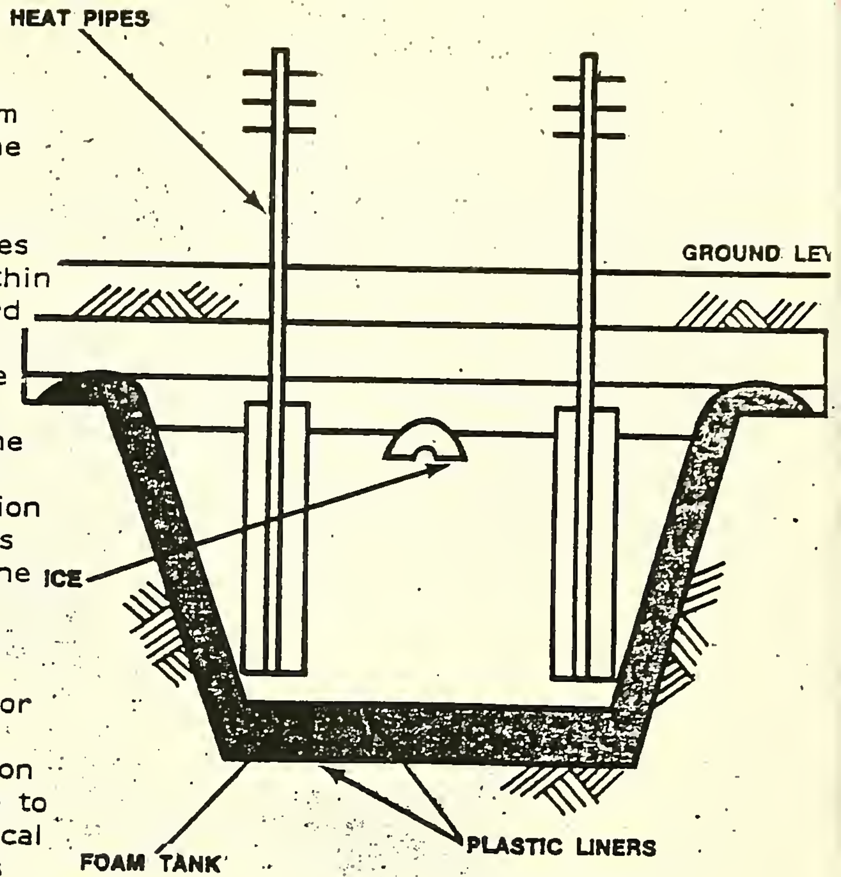


The ice bin has 1300 ft of aluminum finned tubing for its cooling coils. The ½-in. tubing and 3-in. fins are extruded as one section. Same material is used for the outdoor coil. In Knoxville, the ice bin has enough capacity to keep adding ice for the entire heating season, so there is no need for heat input from the outdoor coil. Ice made in winter will last most of the summer for cooling. When the ice has melted, the compressor will run at night to chill the tank's water.

ARGONNE'S HEAT PIPES

A series of heat pipes extend from the bottom of an underground tank of water to above the soil surface; they act as efficient one-way conductors of heat. Along the under-water evaporator section, heat from the water causes thin-film evaporation of the working fluid within the unit. The resulting vapor travels upward and condenses in the above-ground radiator section, releasing the transported heat to the air. During winter the extraction of heat freezes ice along the submerged portion of the heat pipe. When the air is warmer than the water in the tank, the evaporation-condensation cycle stops automatically. The heat pipe thus works as a one-way conductor of heat from the tank to the environment. The ice is thus formed and stored passively in the container.

Roll-bond panels of copper or aluminum, 12" or 14" wide by 8' long have been used for the heat pipes. The underwater evaporator section now consists of a central vertical p.v.c. pipe to which is connected four equally spaced, vertical fins of roll-bond panels upon which the ice is grown. These panels are connected to refrigerant supply and return lines (inside the p.v.c. pipe) which in turn are coupled to condensing panels mounted outdoors. Around the edges of the fin panels, rubber edging is applied to prevent ice from locking on. Each evaporator section is connected to an outdoor condenser section mounted on the wooden structure. A condenser unit consists of four 8' x 34" panels plumbed together. The refrigerant liquid return is at the bottom of the panels and the vapor input line at the top.

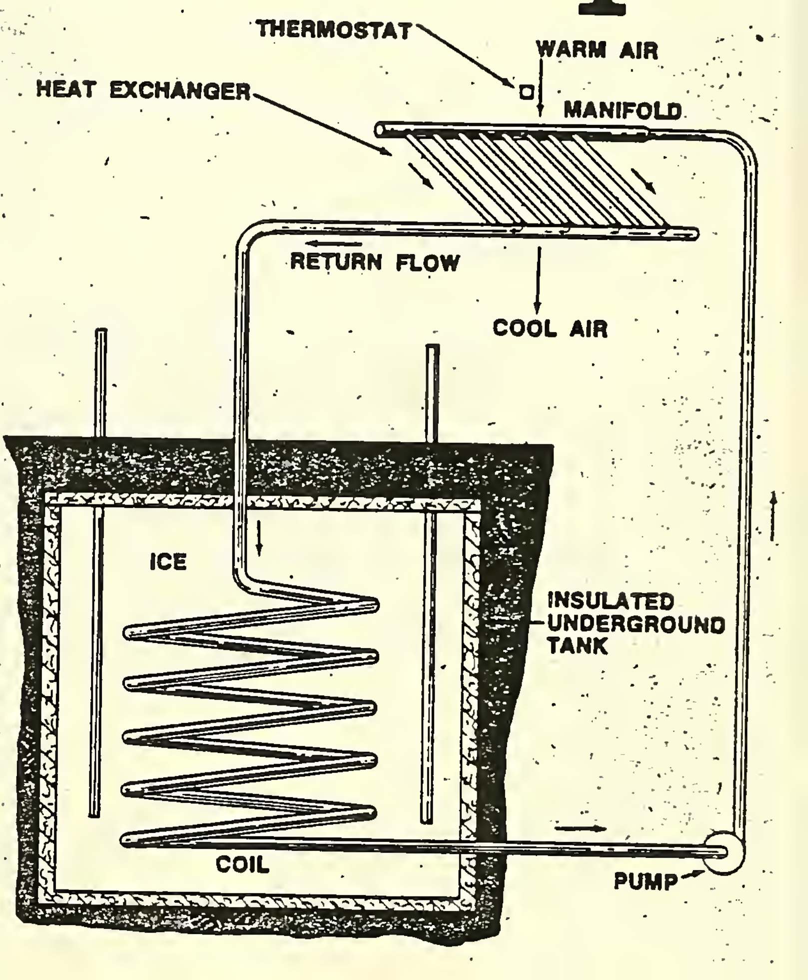


YUAN'S "NICE" SYSTEM

Each heat pipe contains a wick lining extending the full length of the pipe. The wick may be constructed of metal (such as wire screen, sintered metal powder or fiber, or perforated sheets), or of such non-metallic material as felt, cloth, or fiber glass. The wick is saturated with a suitable "working solution" that may require the addition of an antifreeze in some parts of the country.

During the winter, the exposed sections of the heat pipes are cooled by the atmosphere, causing vapor within the tubes to condense. The condensed liquid then flows downward along the wicks to the evaporator section where the heat content of the water again vaporizes the liquid. The warm vapor continues to flow to the top liberating the heat until the water is frozen.

Heat Pipe



For years army engineers have constructed sea ice platforms by free flooding from the center of a thin ice sheet via a submersible pump. A single pump could develop a 500' diameter convexed plane platform, while a multiple pump system could produce an enormous field that might be required for an air runway. Today after the many problems and costs associated with ice makers and ice builders, a modified version of this technique is providing some promise of producing the large quantities of ice necessary for thermal storage uses.

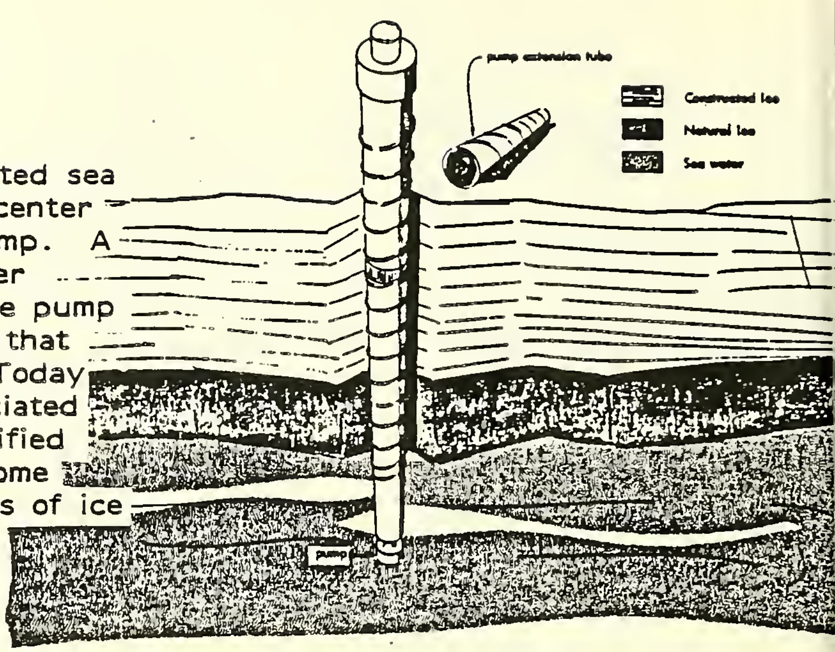
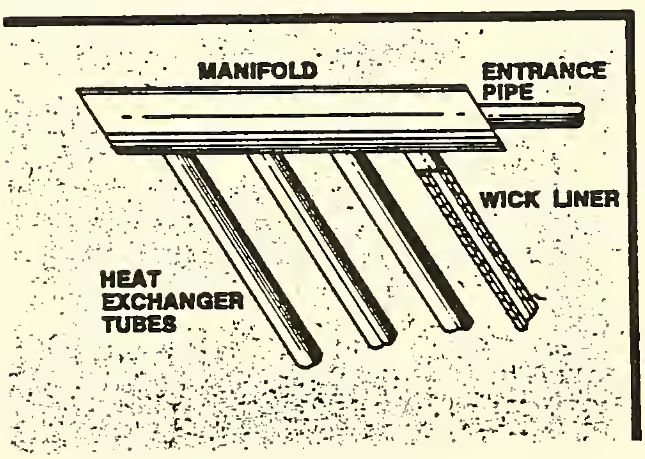
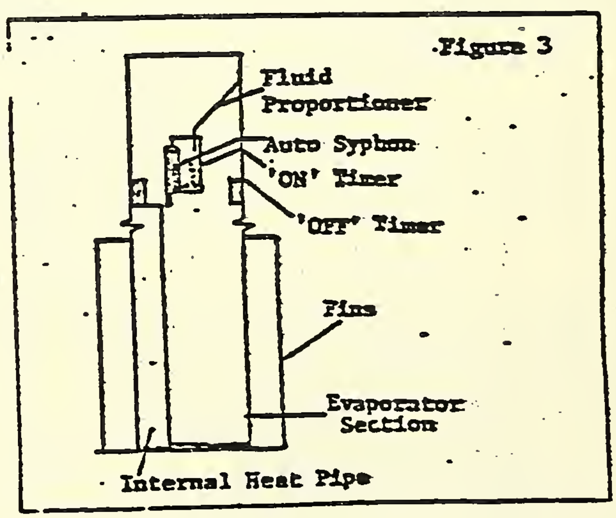
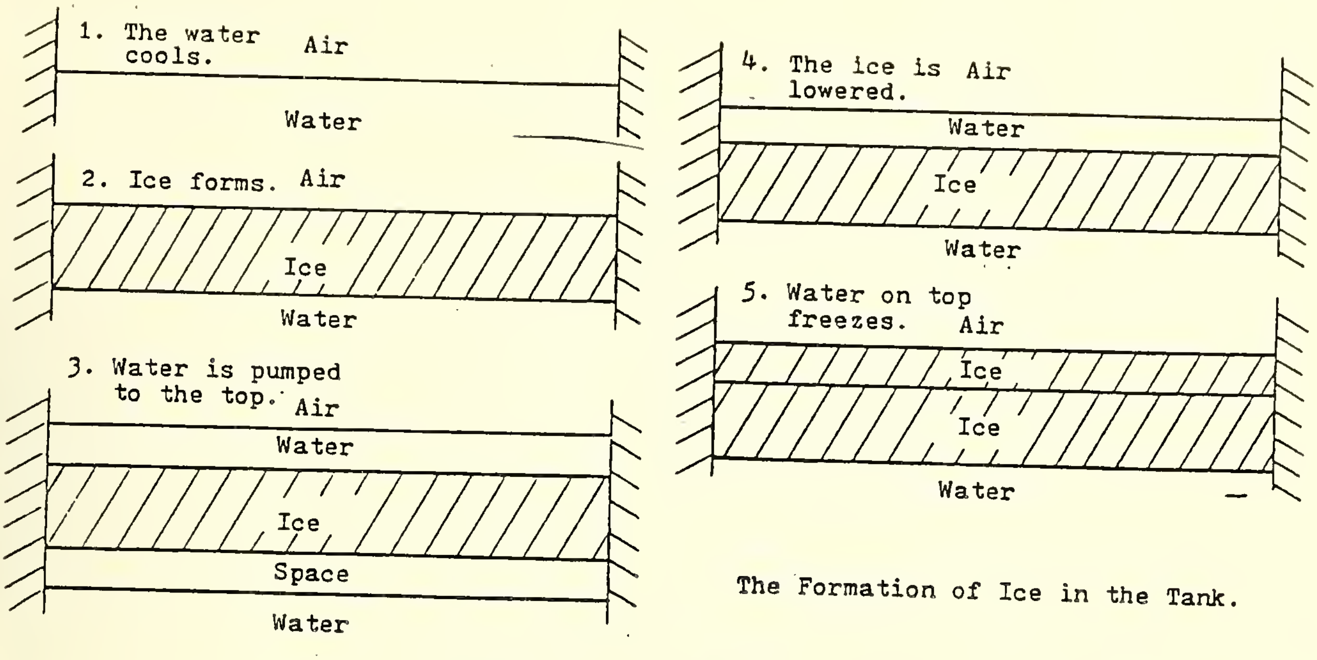


Fig. 4. Electrical submersible pump used for free floo

Yuan's wick pipe Argonne's finned pipe

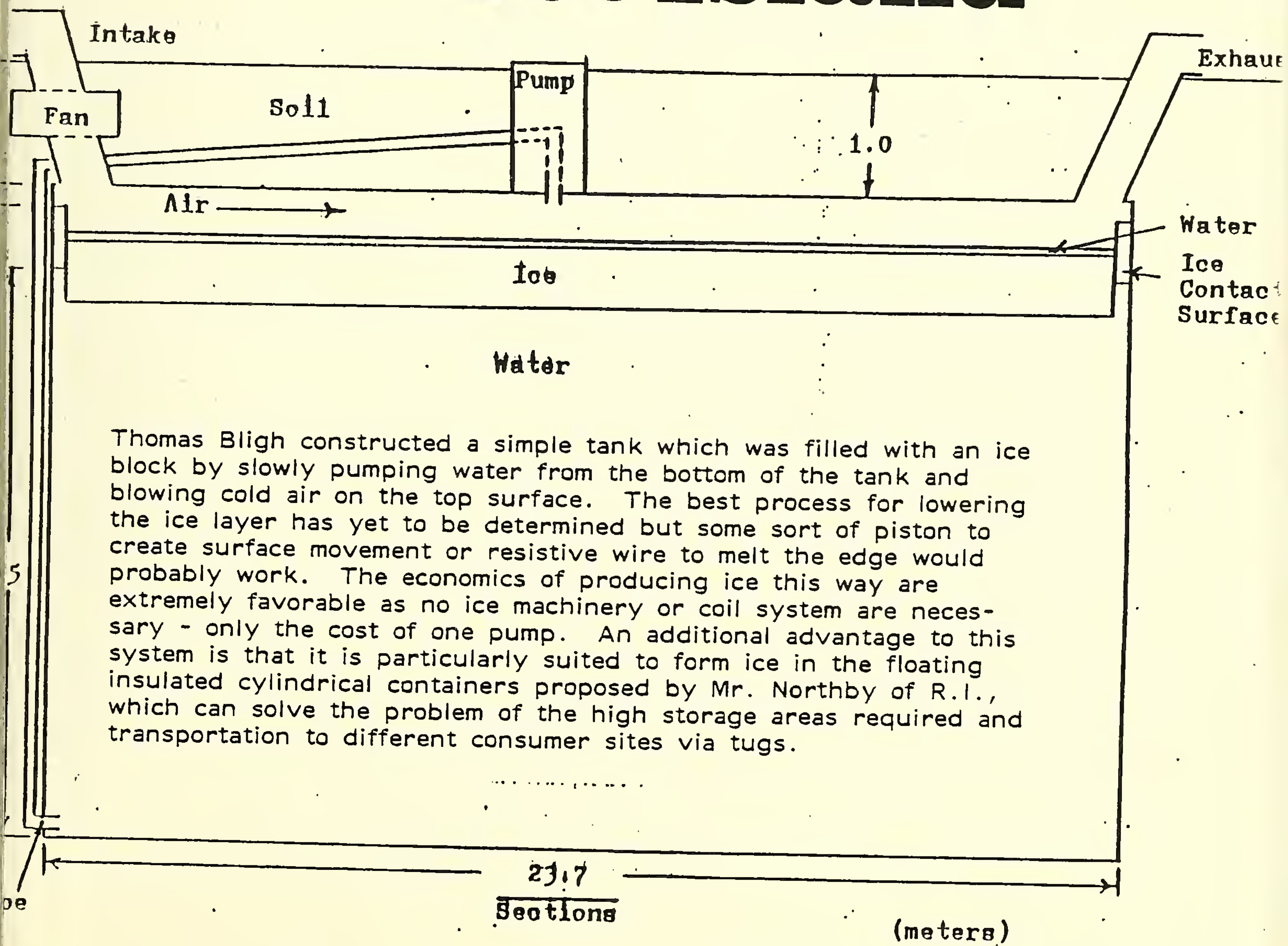






The Formation of Ice in the Tank.

Ice Island



Thomas Bligh constructed a simple tank which was filled with an ice block by slowly pumping water from the bottom of the tank and blowing cold air on the top surface. The best process for lowering the ice layer has yet to be determined but some sort of piston to create surface movement or resistive wire to melt the edge would probably work. The economics of producing ice this way are extremely favorable as no ice machinery or coil system are necessary - only the cost of one pump. An additional advantage to this system is that it is particularly suited to form ice in the floating insulated cylindrical containers proposed by Mr. Northby of R.I., which can solve the problem of the high storage areas required and transportation to different consumer sites via tugs.

STORAGE

The ancients were lucky to be able to save snow and ice in caves or underground trenches. But by the 19th century men were adept at preserving ice through the summer in airtight and insulated, thick or double layered ice houses and ice pits. Today, we can achieve a high R rating with foam in slabs, laminated between other materials or sprayed directly on the object to be protected. If nature has not provided a cave or quarry nearby we can sink a thermal tank underground. As very large volumes would be required for annual storage loads we should look into the possibility of floating the supply in the ocean to service urban ports such as Boston, NY, Miami, or LA. In Boston we must look carefully for underutilized industrial parcels near the downtown, large quarries, vacated underground storage tanks, and abandoned subway tunnels and stations.

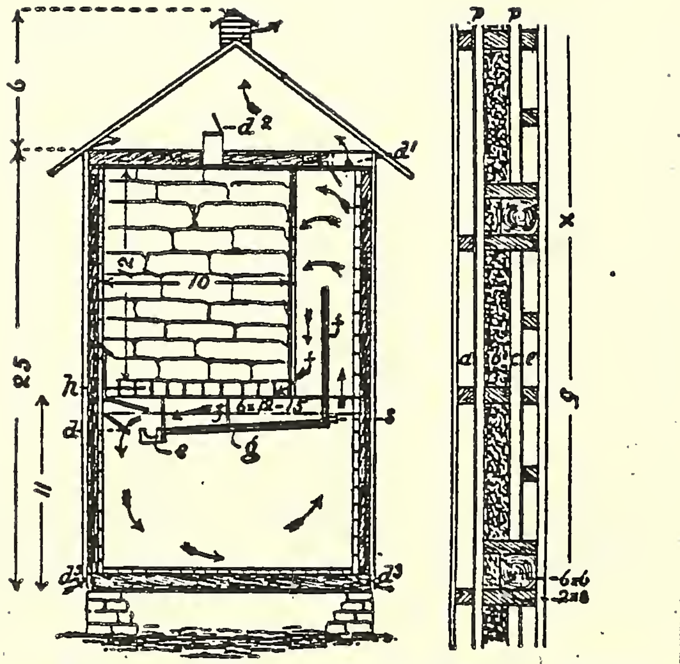
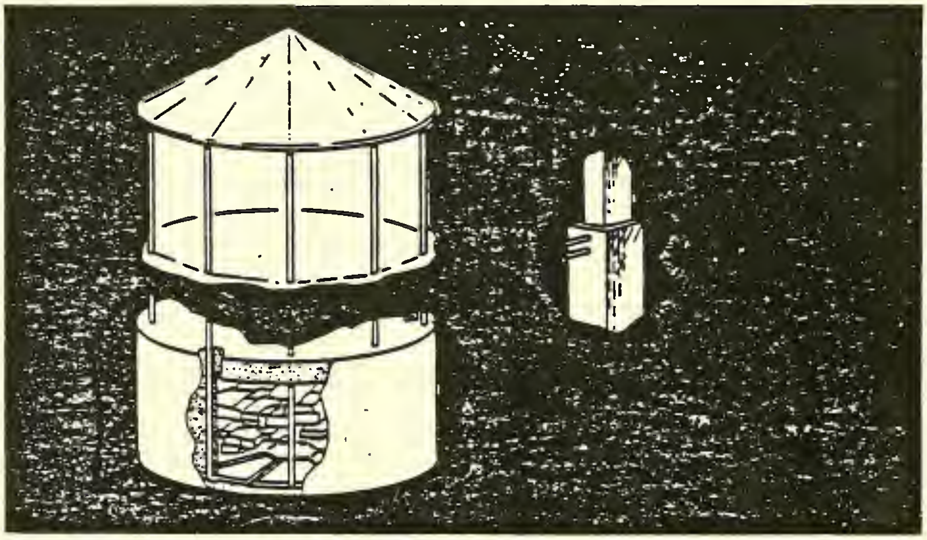


Fig. 68. Section of House. *Fig. 69. Section of Wall.*

PRINCIPLES OF COLD STORAGE CONSTRUCTION.



In winter (left) ice forms inside a large insulated storage tank. In summer (right) ice and cold water in the tank can be used to cool a home by pumping water from the tank to the home.

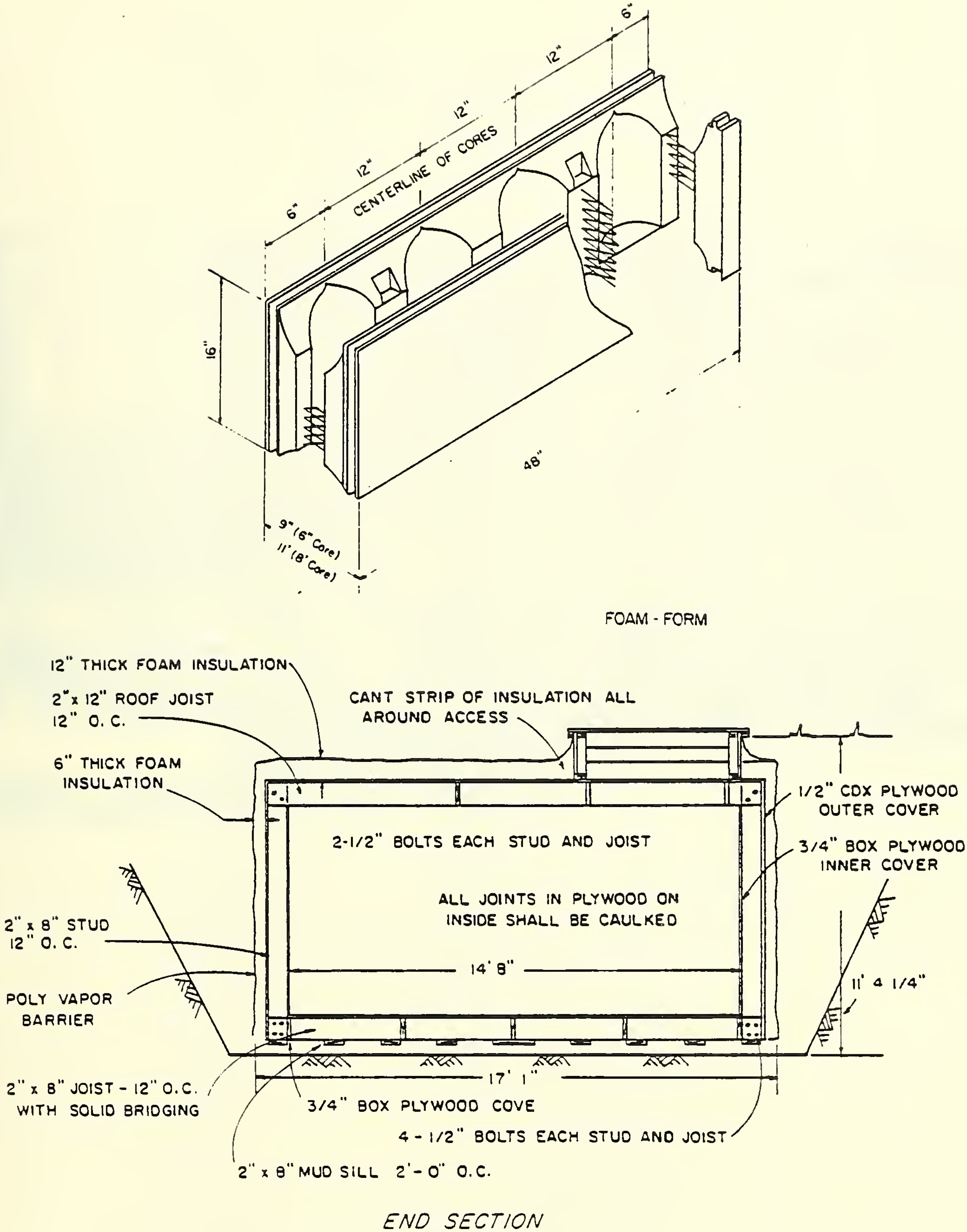
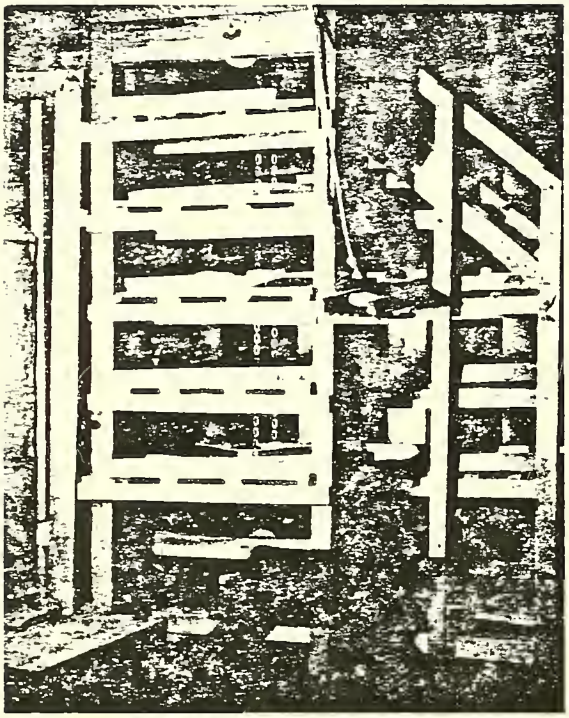
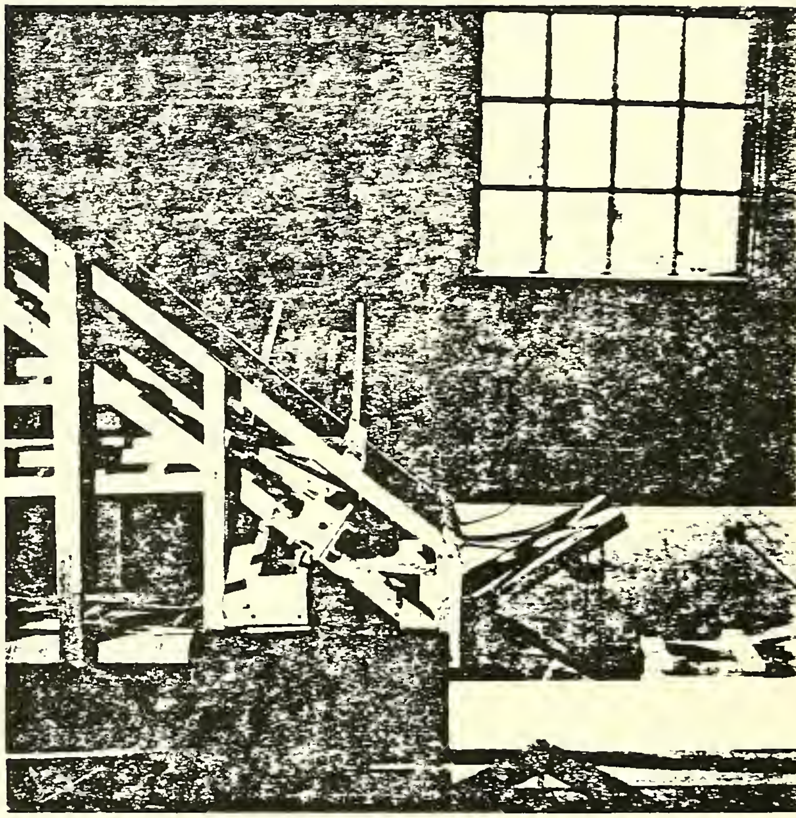


Figure 1. Wood Frame and Plywood Tank for the Experimental NICE/AC System in Edina.





47-48. IF YOU WILL study this pair of photos of a section of the ice house model showing side views of the inner structure of the elevator, you will see the chain running down from the top of the tower through the centers of circular turns at every eight-foot level and extending at ground level to the right back to the elevator apron (Illustration 48). The runs on these turns around the chain were slanted sufficiently to insure the ice's continued movement after it slid from the elevator onto the run that led by the doorways of the rooms being filled.

At each run level broken or dirty blocks were discarded and taken out by the waste ice run that can be seen at right angles to the elevator chain in Illustration 47.

The chip chain, run by the same power as the elevator chain, can be seen above extending out from under the first part of the incline.

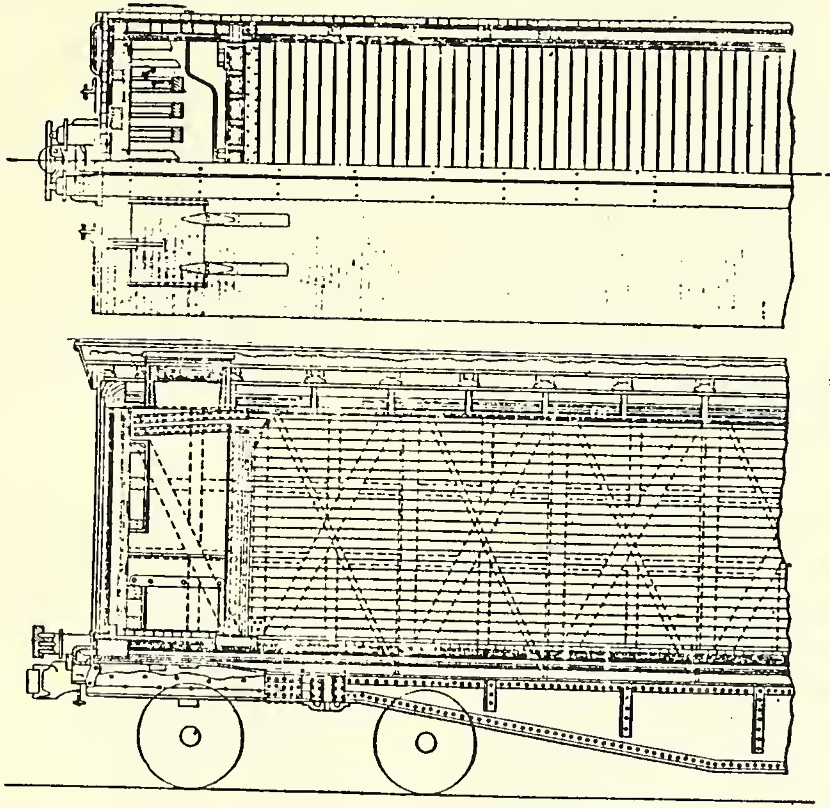


FIG. 4.—Refrigerator Car.

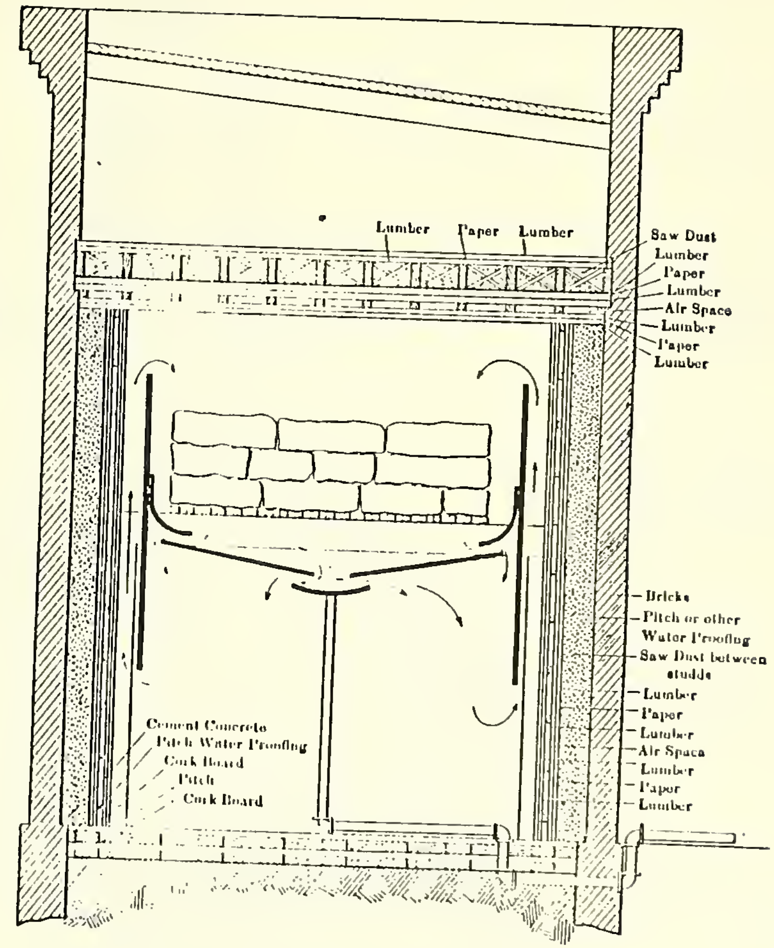


FIG. 2.—Jackson System of Cold Storage.

metal inte-
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galvanized
gauge type
s steel.

rd size in-
lab panels.
are first to
by Factory
rance Sys-
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lation to re-
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when re-
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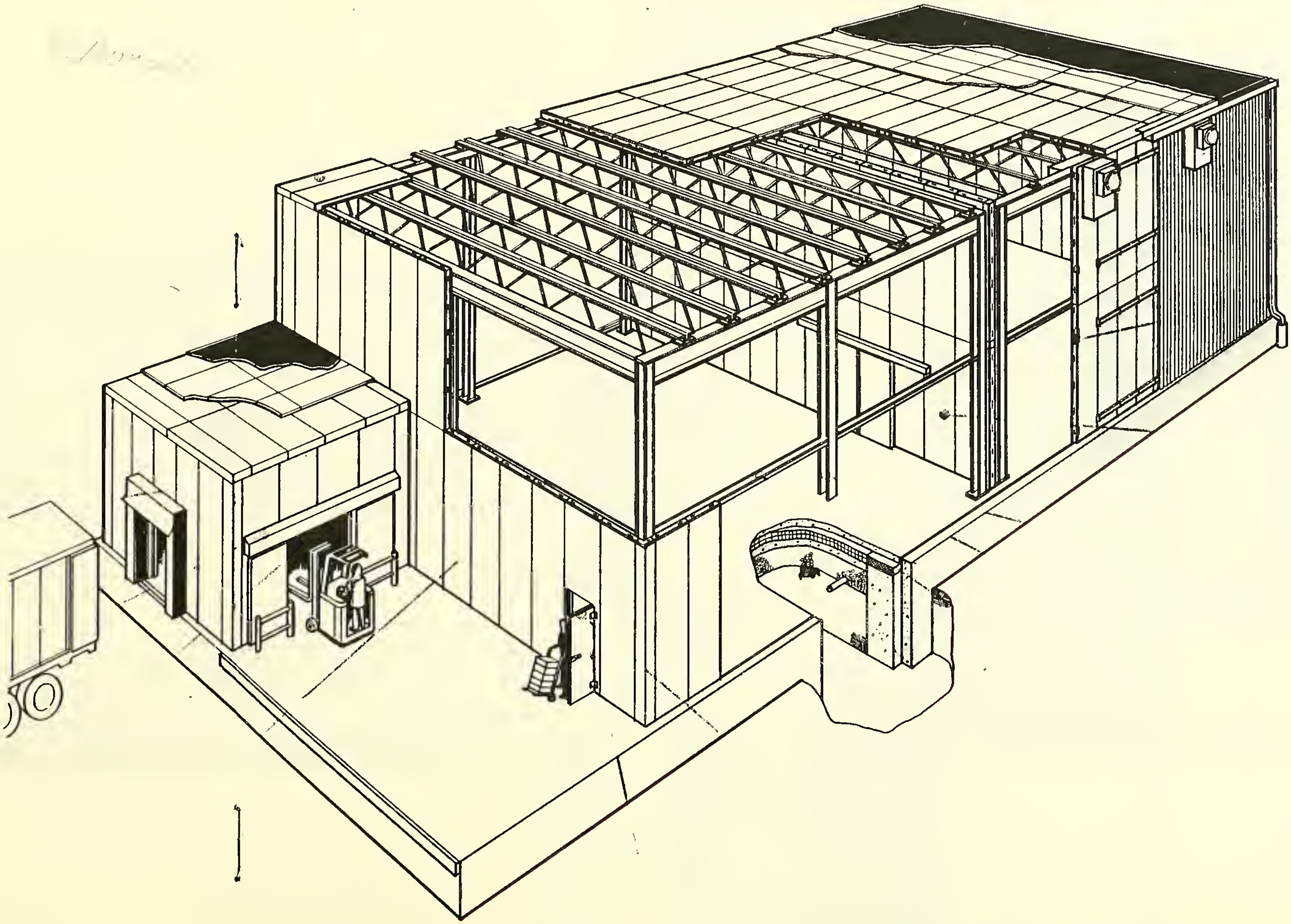
nels to in-
or to dis-

Open-web steel joist roof construction. In northern zone snowload areas steel is appropriately heavier.

Load bearing steel beams carry load to "H" columns.

Built-up insulated roof by others. Bally furnishes construction details and guideline drawings.

Self-contained refrigera
tion system — sid
mounted type. To
mounted units are als
available. The system
include condensin
units, blower coil and a
necessary controls.



Optional color coat
metal facade availab
in six colors and whi
for any portion of t
Building.

Tongues and grooves
panel edges a
"foamed-in-place". A
sures user of a tig
seal.

Partition to form sep
rate compartments
made of prefab insulat
panels.

Slab urethane insulati
is recommended for
stallations requiring
built-in floor.

"H" columns supp
load bearing beams

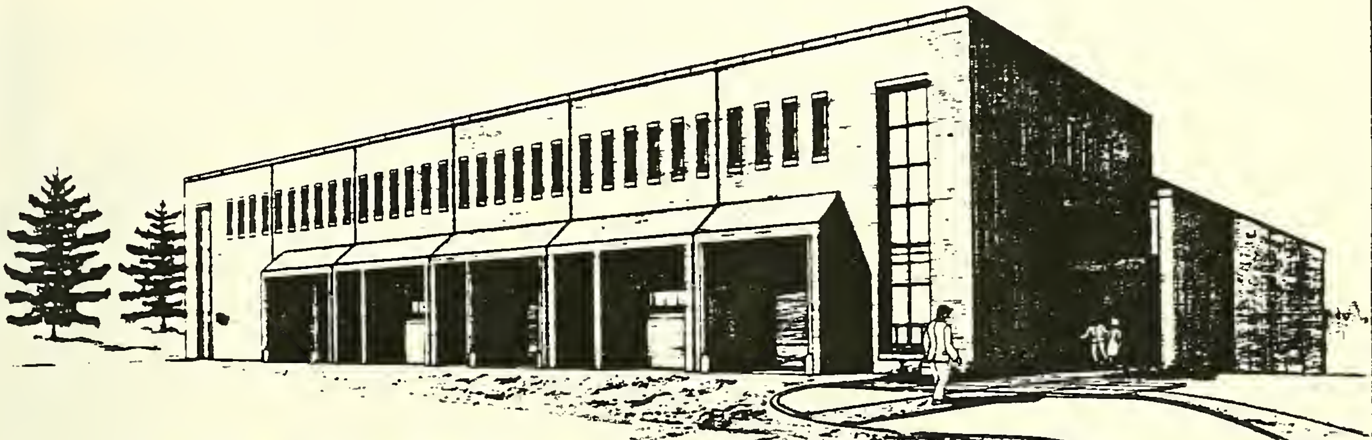
Horizontal steel str
secure vertical wall
building steel.

Cut-away view of 50' x 100' x 22'

Anti-sweat heaters concealed beneath door jambs and under door edges prevent conden-

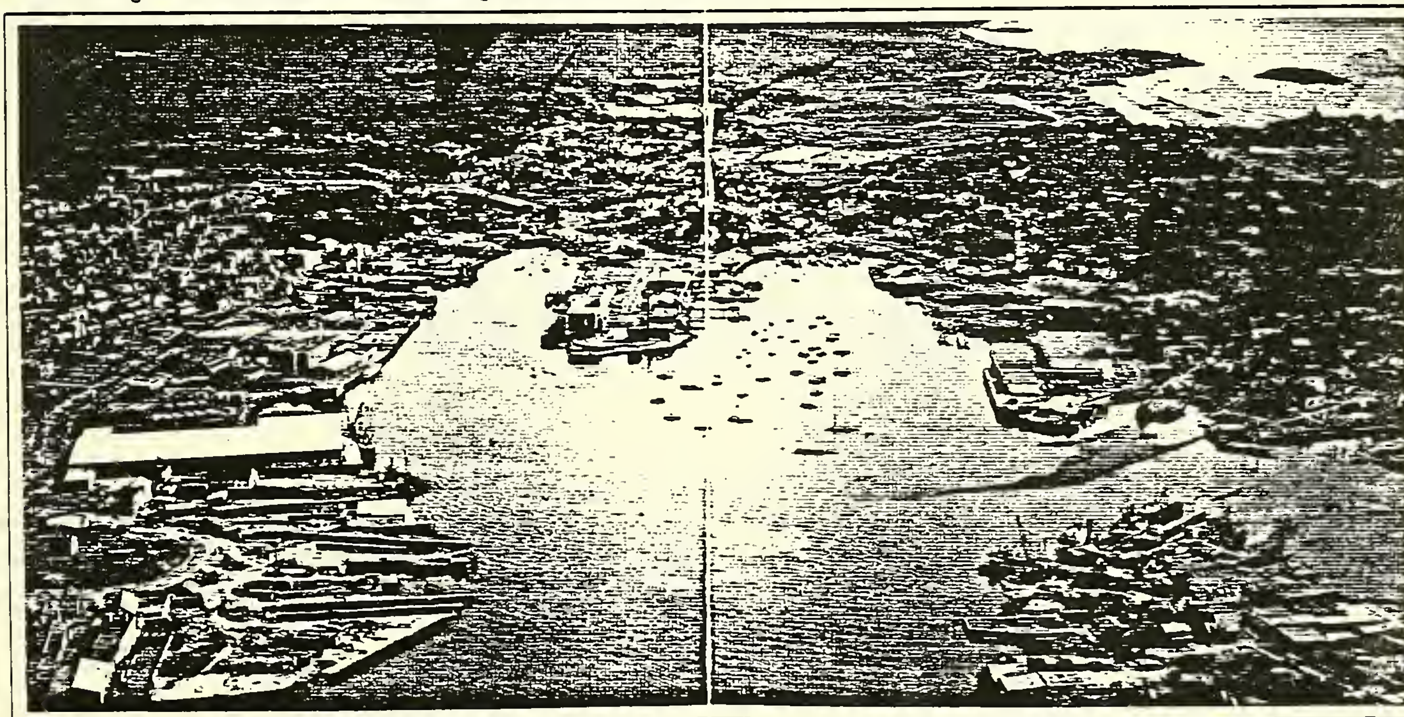
Hinged 34" x 78" self-closing entrance door (other sizes available). Contains inside safety release to prevent anyone from being locked

Outdoor installations require special piers, fo
ings, foundation slabs and subfloors. Bally s
plies guideline drawings and specifications,
cept the depth of footings and piers which m
be determined by local climate and soil c



CRREL- The Cold Regions
Research and Engineering Laboratory
of the Army Corp of Engineers
in Hanover,New Hampshire.
Center for ice engineering
which seeks to analyze,
develope techniques,and design
solutions to ice problems.

Gloucester Division
World's Largest Frozen Seafood Processing & Distribution Center



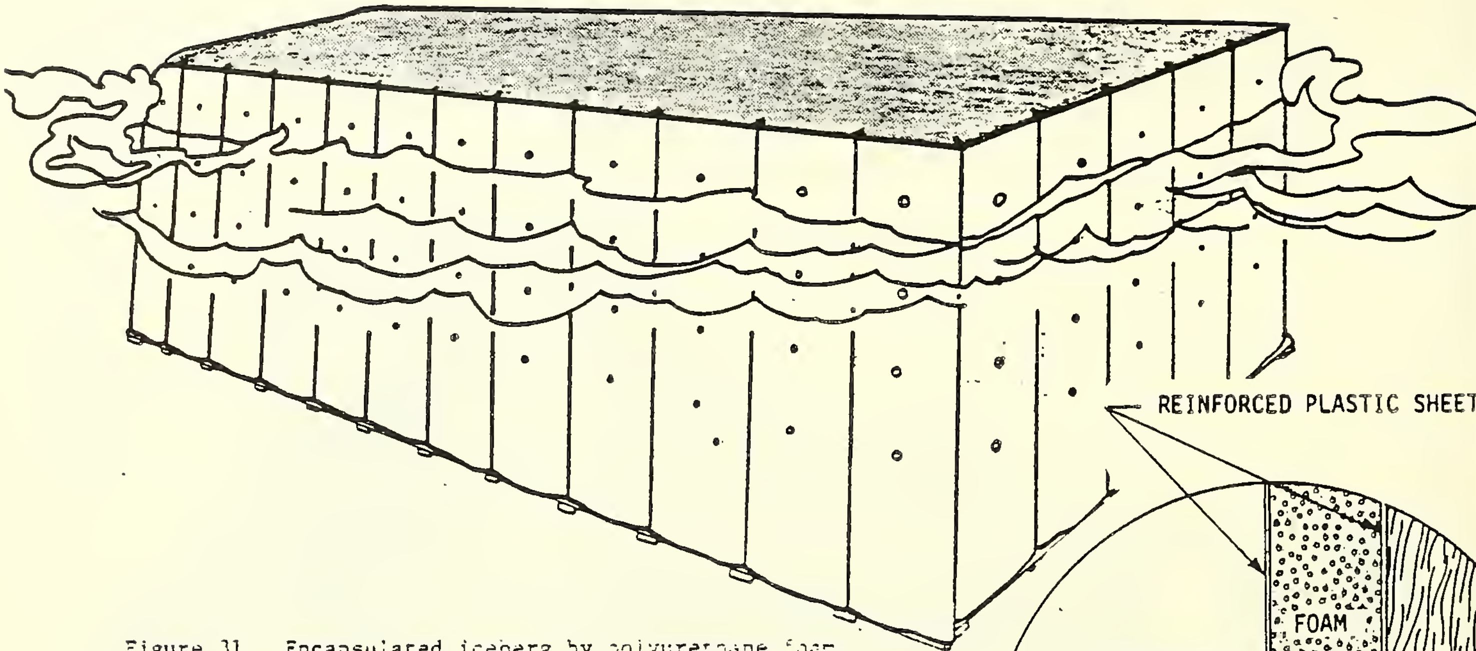
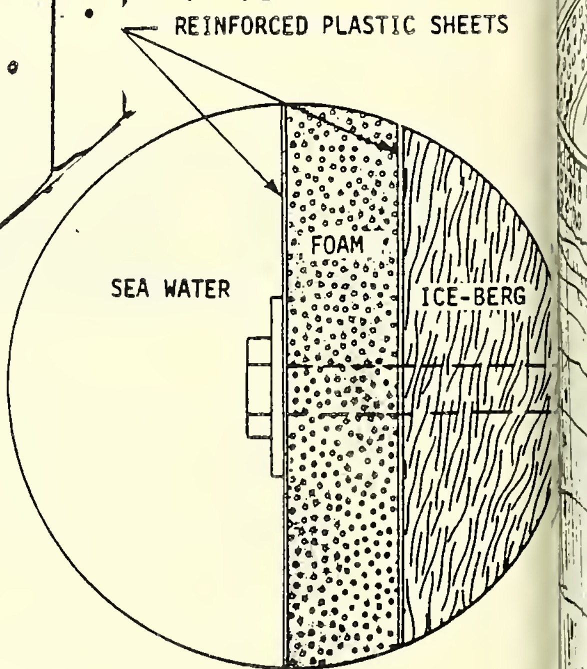


Figure 31. Encapsulated iceberg by polyurethane foam



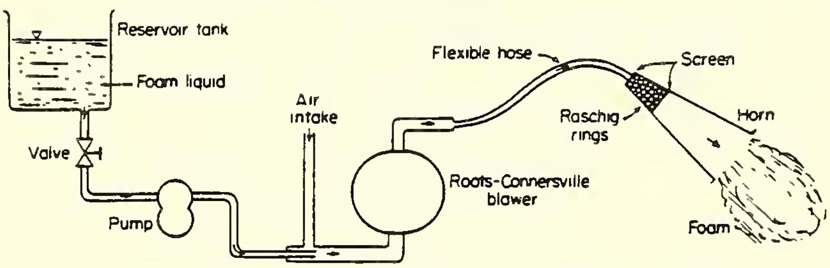


Fig. 1. Simplified schematic of foam generator (pump and blower are driven by the same 5-hp gasoline engine).

Fig. 30 Use of stud as an attaching mechanism of polyurethane panels to the iceberg.

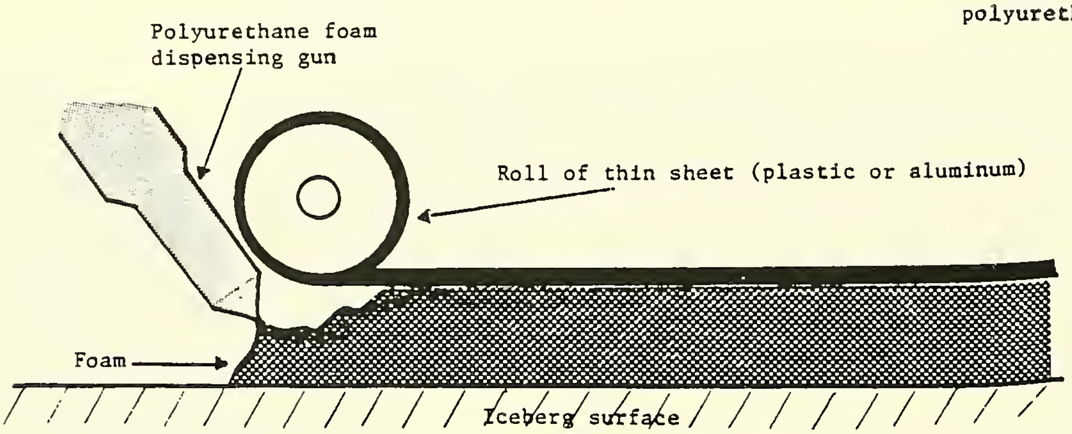


Figure 22. A closeup view of the process of insulation of the top surface

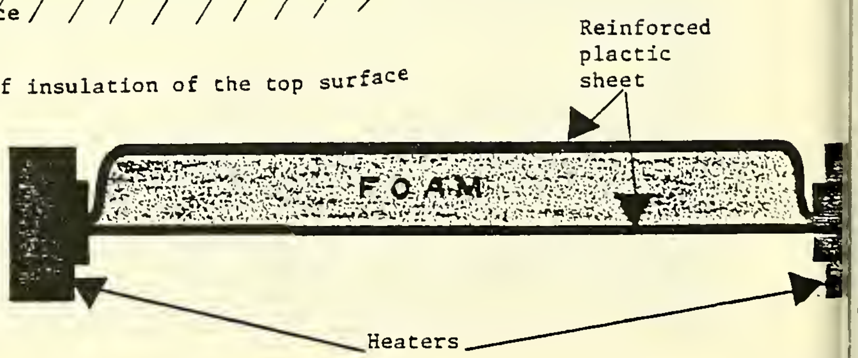
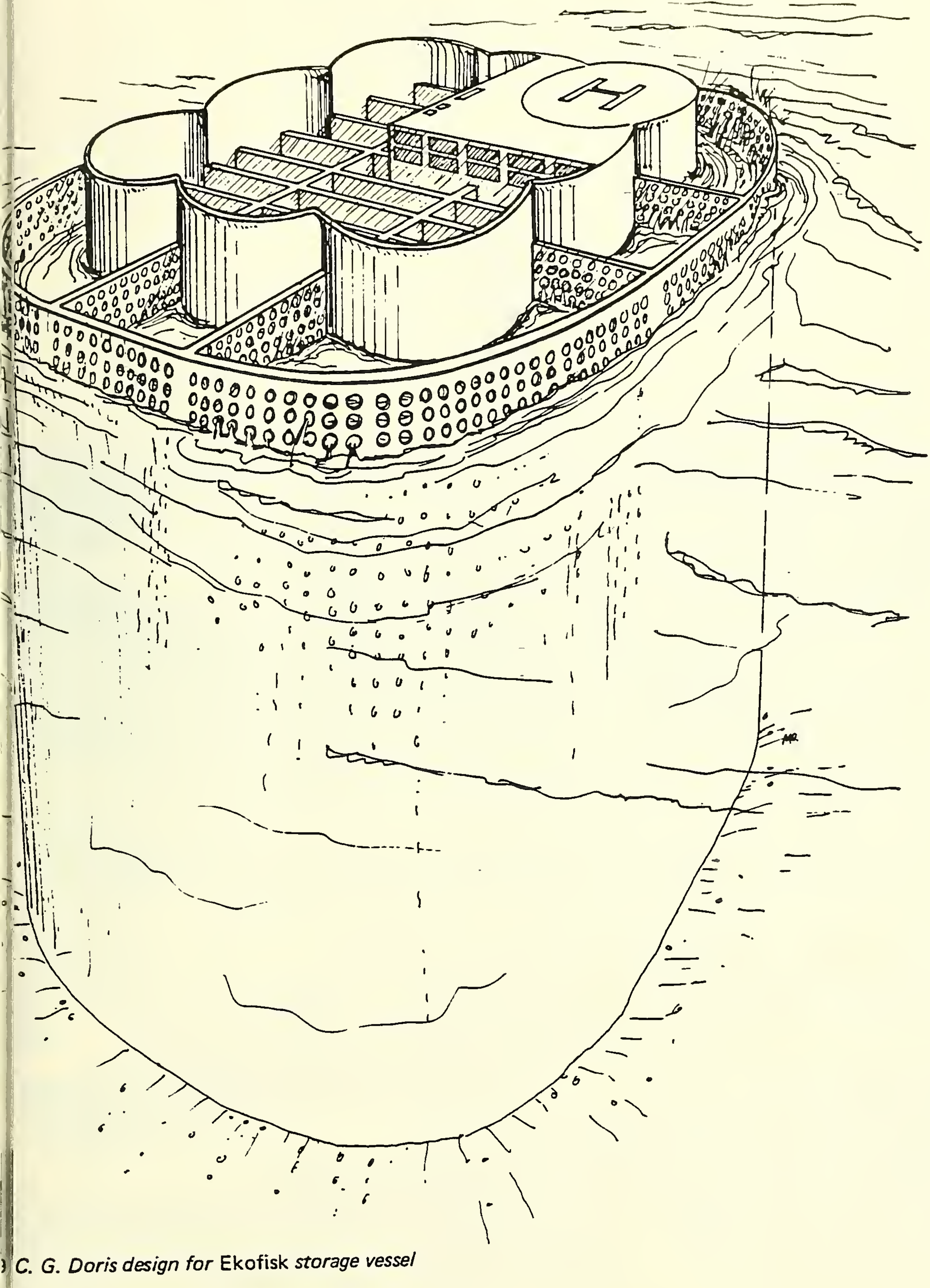


Figure 24. Heat sealing method of laminated polyurethane foam



C. G. *Doris design for* Ekofisk *storage vessel*

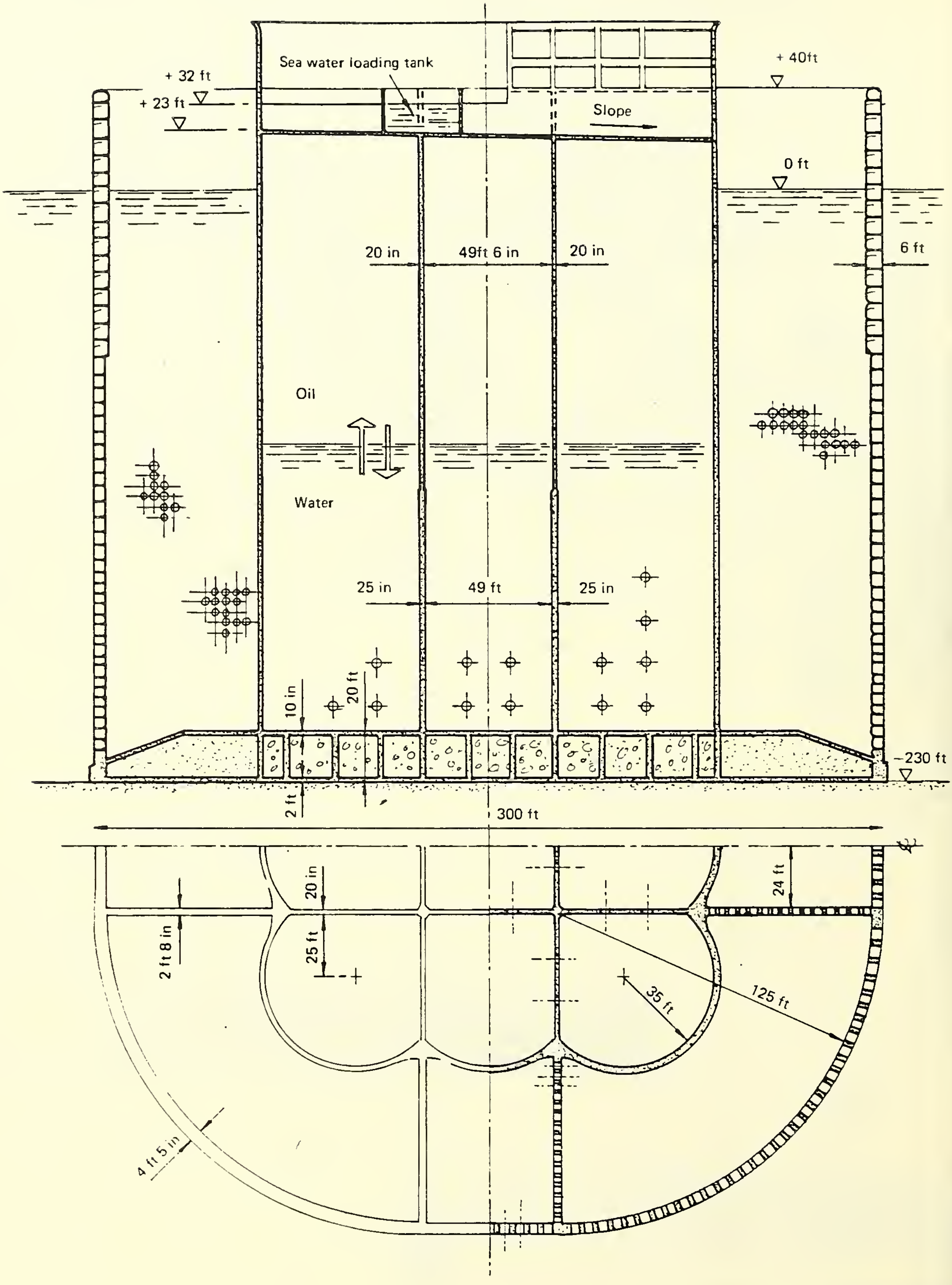
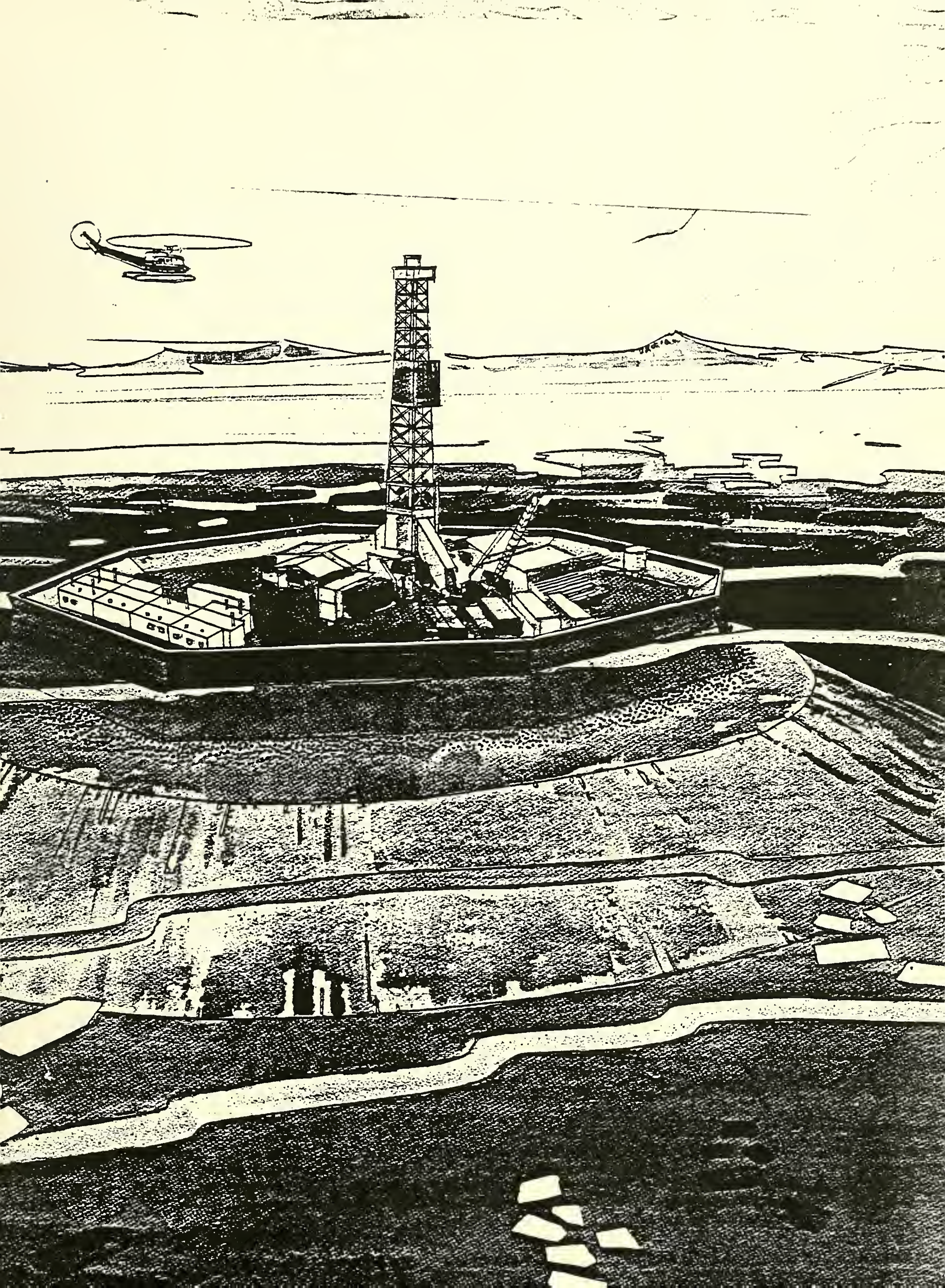


Figure 10 Ekofisk *storage vessel overall dimensions*

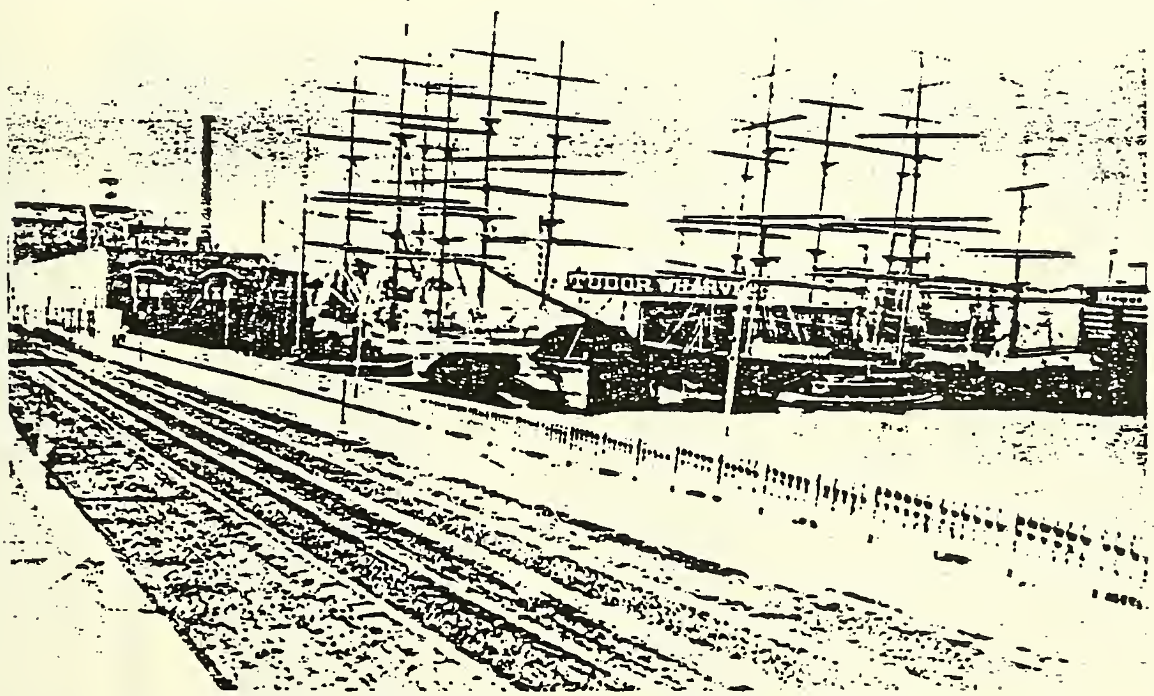


TRANSPORTATION

TRANSPORTATION

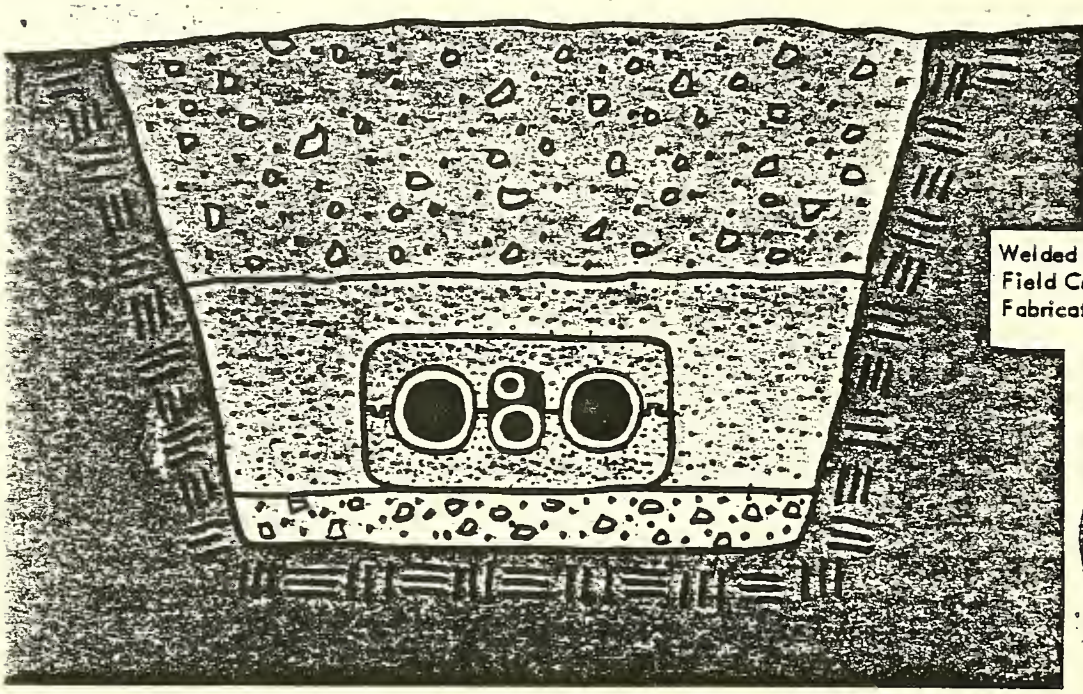
After an extended journey in a railroad car or a clipper ship, the ice of yesteryear was delivered to the consumer in a quaint looking ice wagon. As we have been on mechanical cooling for sometime now, we are just beginning to look at different methods of transporting this commodity. Insulated pipes can carry chilled water for quite some distance with minimum heat gain. The "ice slinger" of old still moves large quantities of flaked ice via flexible pneumatic hosing. Meat and produce warehouses in market areas used to be serviced by buried lines.

There is potential in Boston for using ice as cargo for trips south as many ships, containers, and trucks leaving Boston are empties. Large volumes of ice could be floated to southern ports and extensive research on transporting iceburgs has begun.



SHIPS LOADING ICE AT TUDOR WHARF, CHARLESTOWN, MASS.
Rather than continue to lease Gray's Wharf, Frederick Tudor bought the wharf shortly after Captain Barry's time, changing the name to his own. The scene in this later-day photograph is undoubtedly much the same as when Captain Barry took on ice here in the ship *Delhi* during December 1836.

Photo courtesy The Peabody Museum, Salem, Mass.



'ig.4. Design of the trench when the pipe is insulated with Wirsbo-PUR. The total thickness of the backfill above the insulation should be about 20" (50 cm).

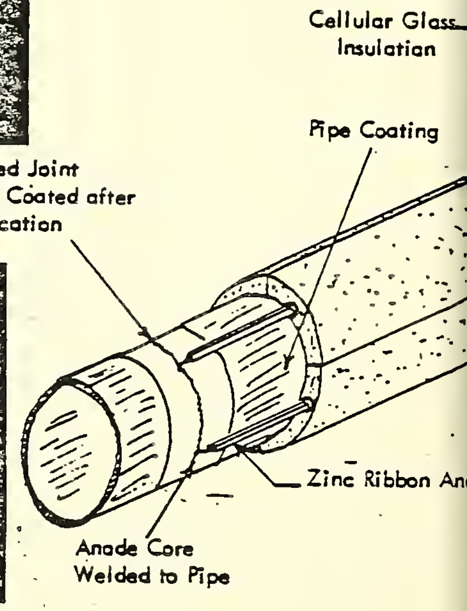
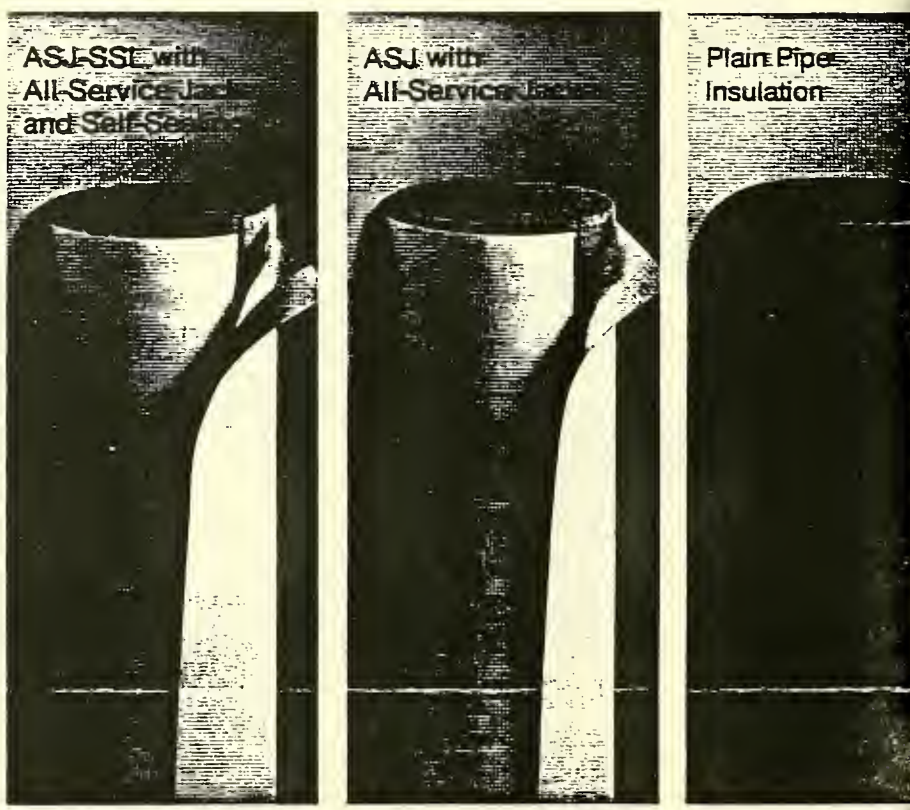


Figure 3
Cathodic Protection of Cellular Glass
Insulated Steel Chilled Water Pipe

...: Pipe Insulation is produced in three foot sections for iron pipe sizes ½" to 30" (1.27 cm to 76.2 cm) and copper tube sizes from ⅝" to 6⅛" (1.5 to 15.56 cm). Available wall thicknesses are from ½" to 6" (1.27 cm to 15.2 in single layer (for most sizes).



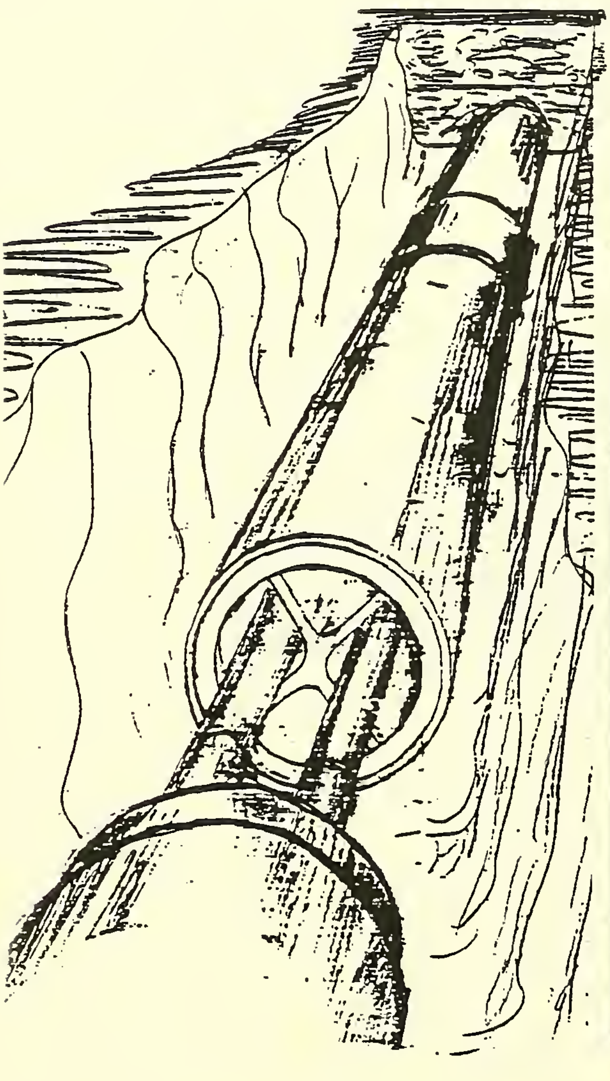


FIG. 12. ASBESTOS CEMENT PIPE CULVERT

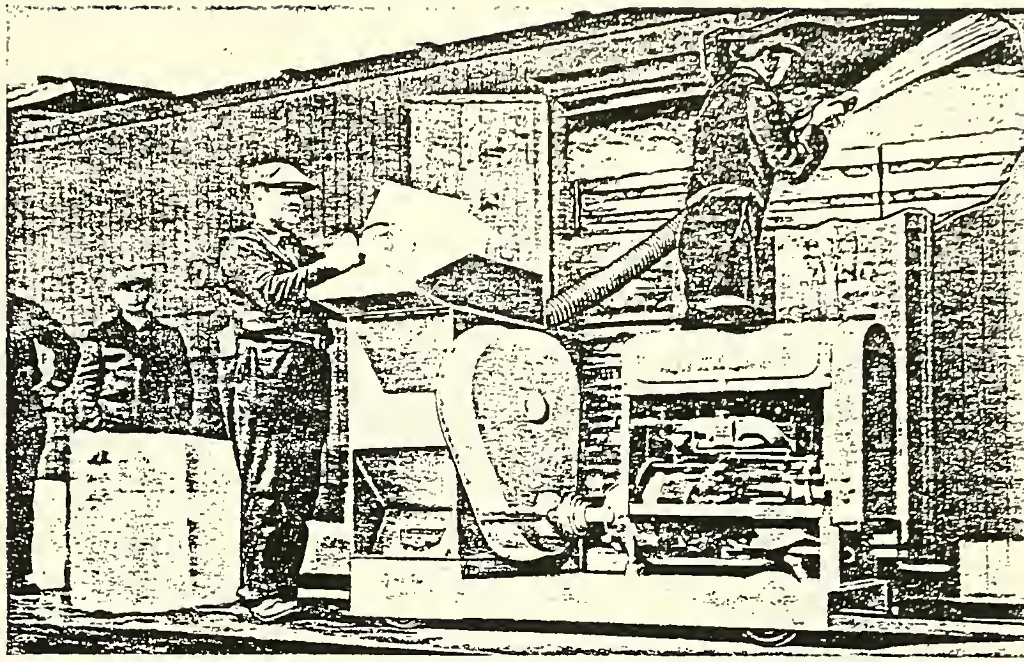
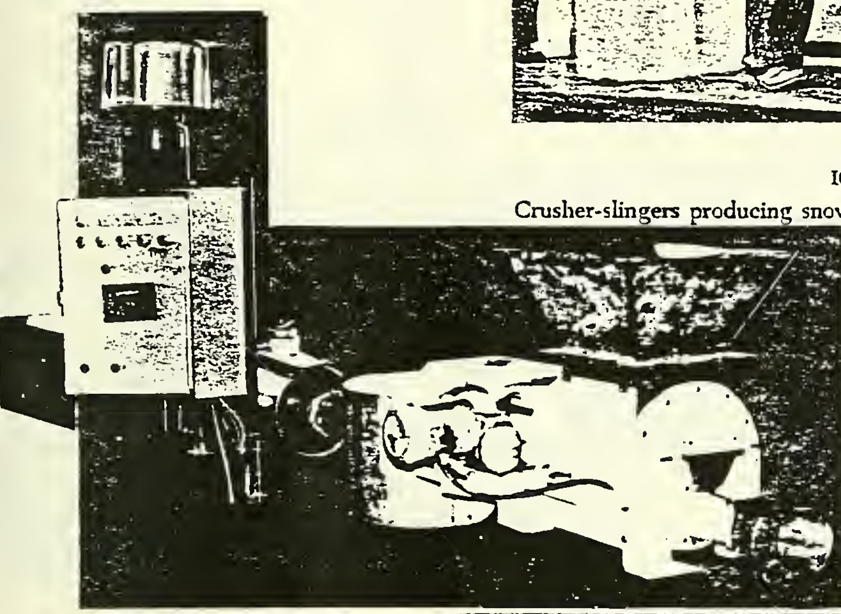


Photo courtesy Link-Belt Company

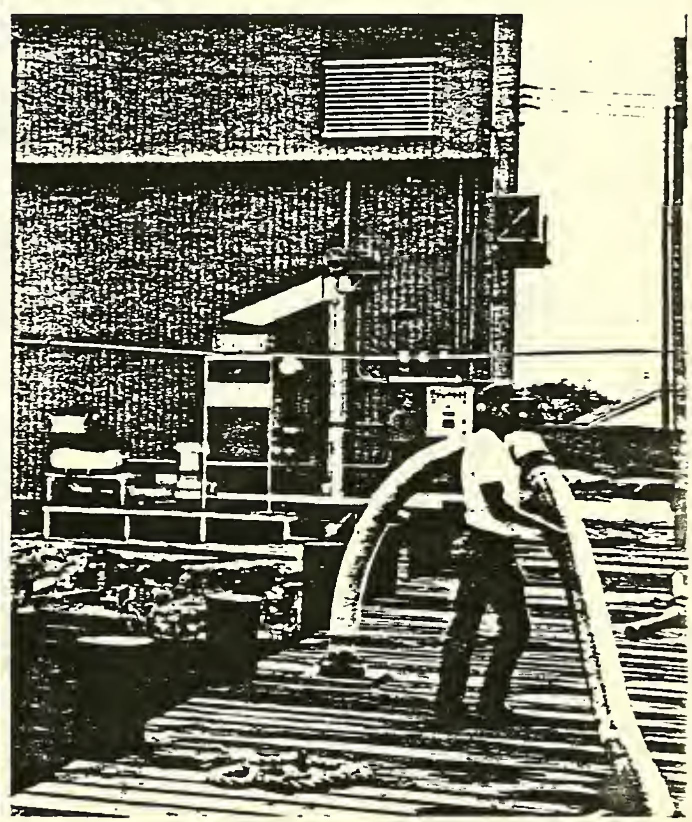
ICING WITH A CRUSHER-SLINGER

Crusher-slingers producing snow-ice for use in icing refrigerator cars exemplify twentieth-century progress in refrigerated transport.

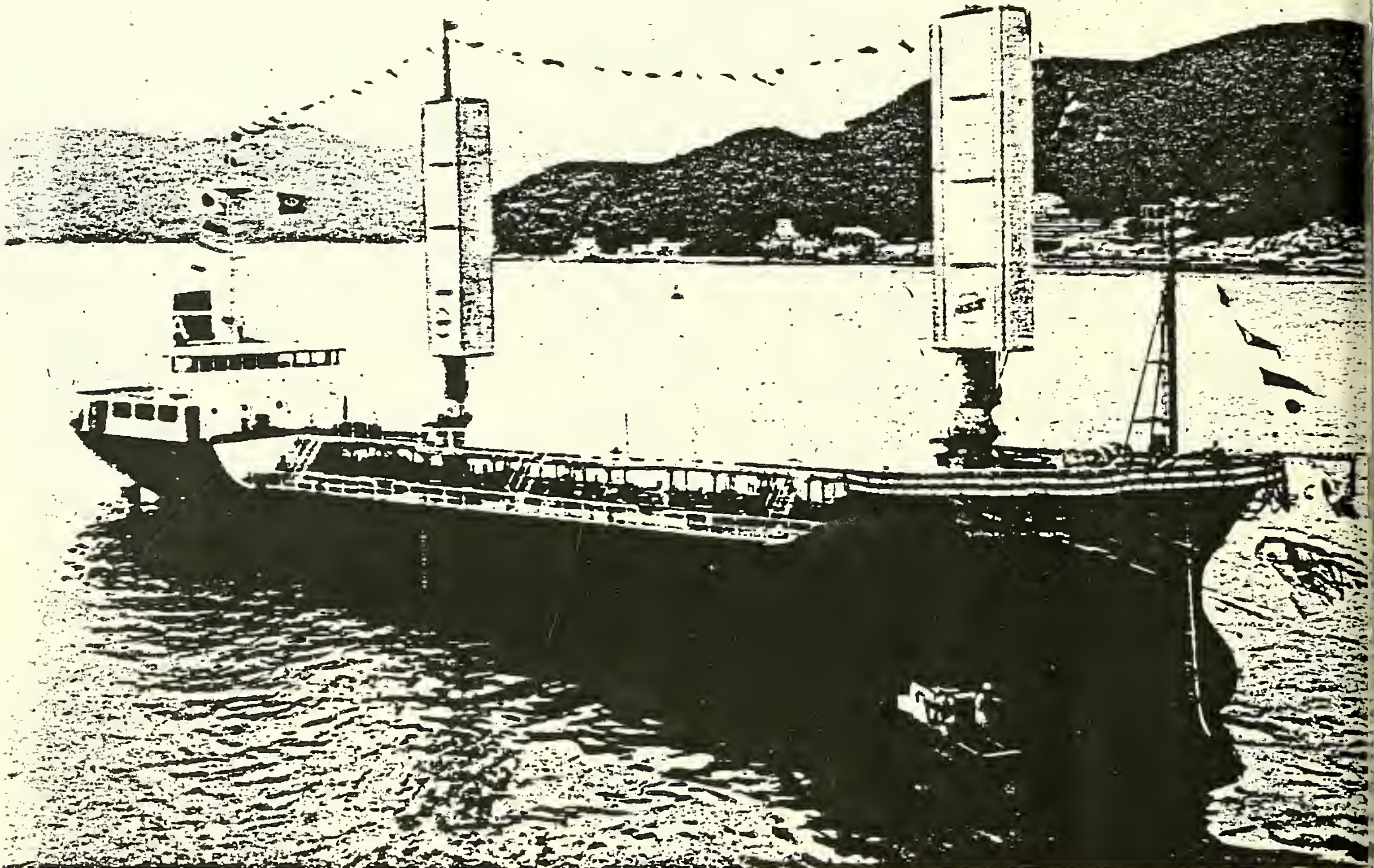
PNEUMATIC ICE CONVEYOR



This man is directing ICE CHUNKS into the ice storage hold of the ship. Note how easily he can control this 5" flexible tube.



Shown above, is how this flexible tube comes from the storage bin to the hold of the ship.

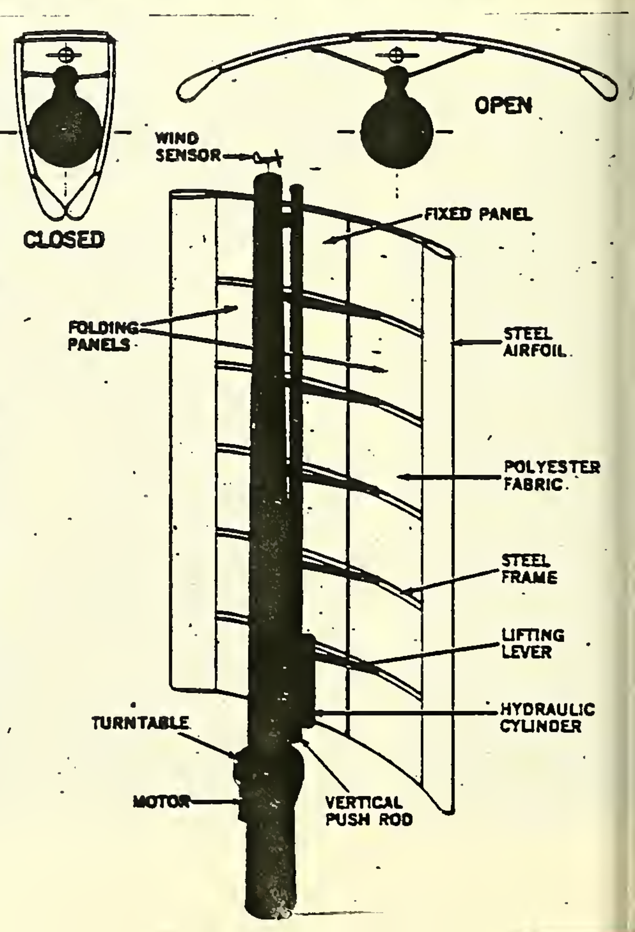


sailing ships

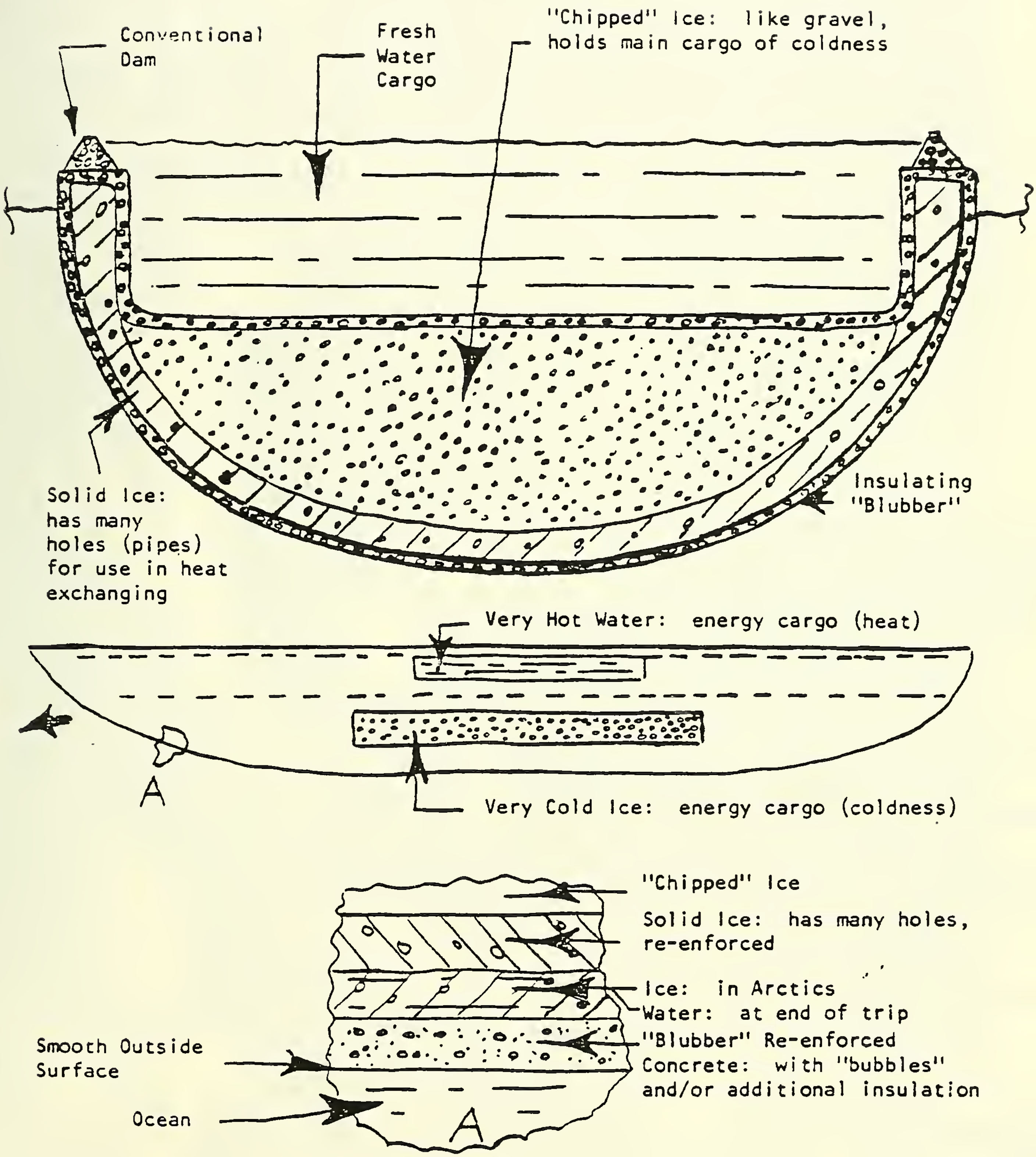
Wind-powered merchant ships mate an ancient art with advanced technology to cut fuel costs

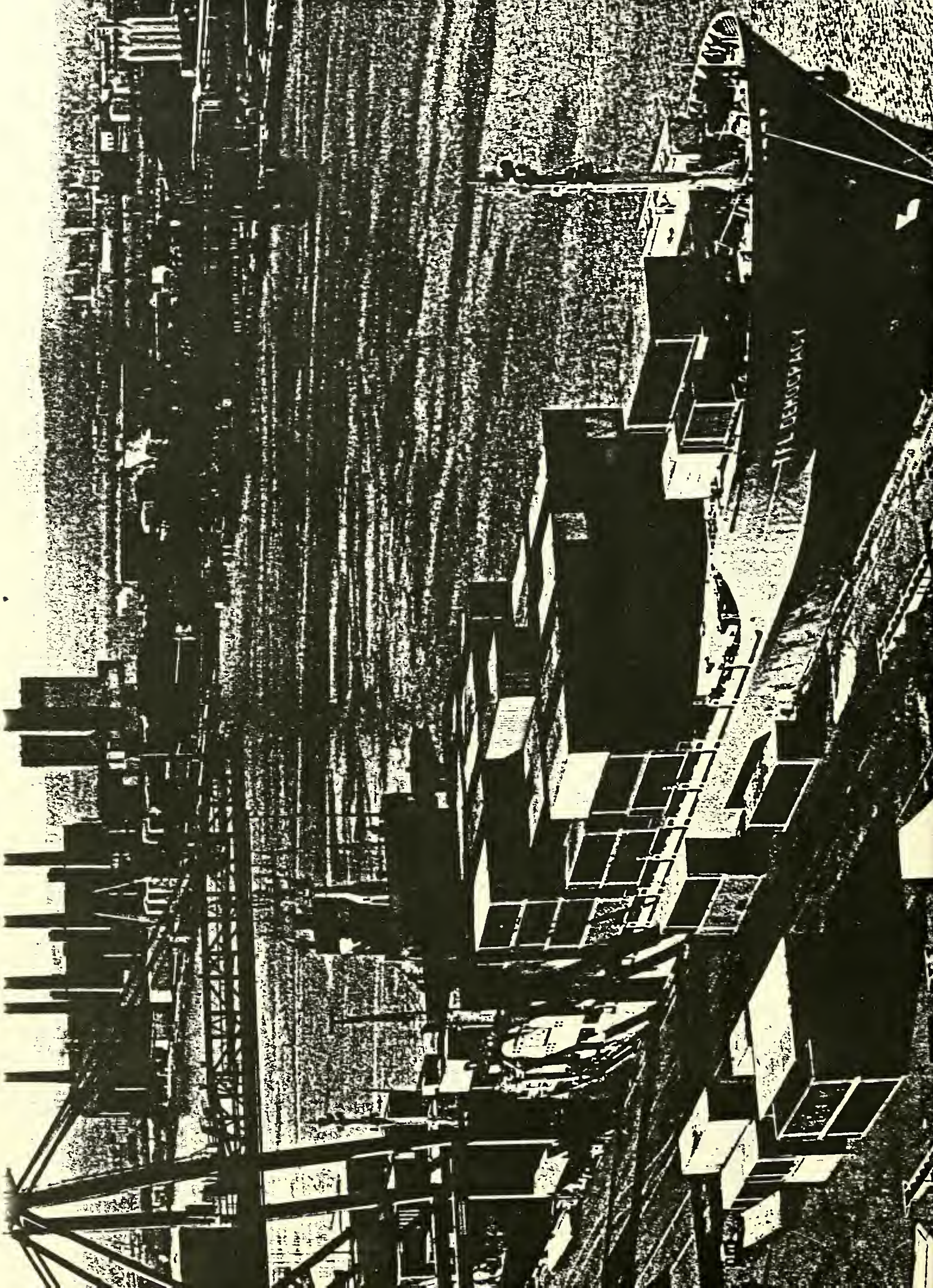
Steel-and-polyester sails soar above the deck of the modern, 217-ft.-long *Shinaitoku Maru*. The relatively small (2100 sq. ft.) sail area can generate enough thrust to assist the tanker's engine. Computer-controlled sails are monitored from the pilot house, which also has manual override controls for sails.

Three-part sail has two folding wings hinged to a rigid, mast-mounted panel. Like an umbrella's ribs, levers hold the sail open and push up (under hydraulic power) to fold sail. A turntable rotates the mast, setting sails at best angle to the wind. Sensor atop mast feeds wind-speed and direction data to a computer that controls turntable motor and sail hydraulics.



ICE BOAT


Conventional Dam
Fresh Water Cargo
"Chipped" Ice: like gravel, holds main cargo of coldness
Solid Ice: has many holes (pipes) for use in heat exchanging
Insulating "Blubber"
Very Hot Water: energy cargo (heat)
A
Very Cold Ice: energy cargo (coldness)
"Chipped" Ice
Solid Ice: has many holes, re-enforced
Ice: in Arctics
Water: at end of trip
"Blubber" Re-enforced
Concrete: with "bubbles" and/or additional insulation
Smooth Outside Surface
Ocean
A



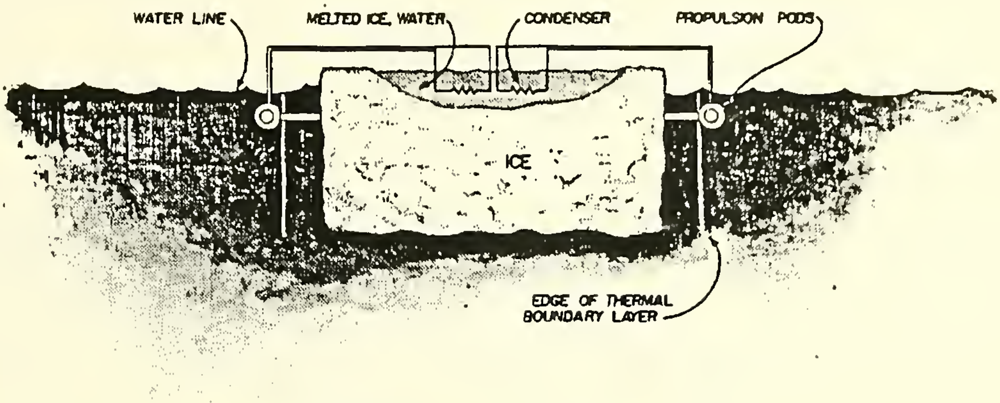


Fig. 2. Installation of propulsion pods and condenser in iceberg

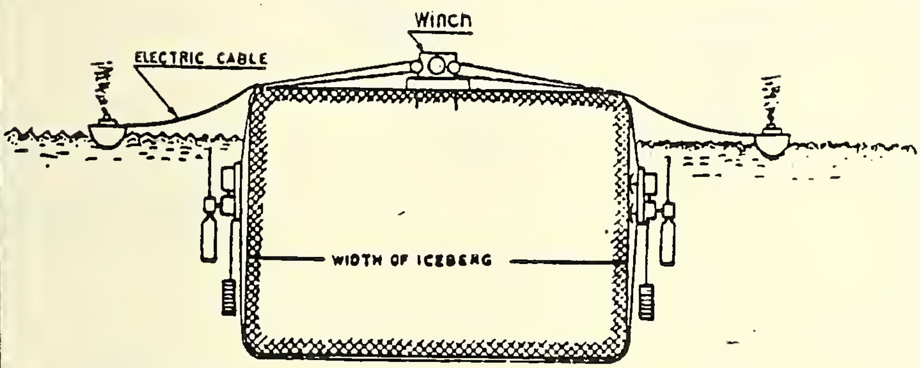
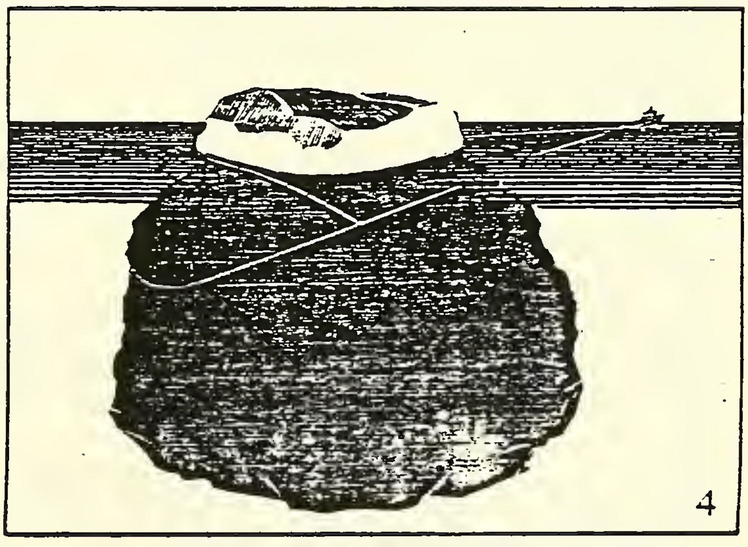


Fig.(2) New Paddle-Wheel Propulsion Method



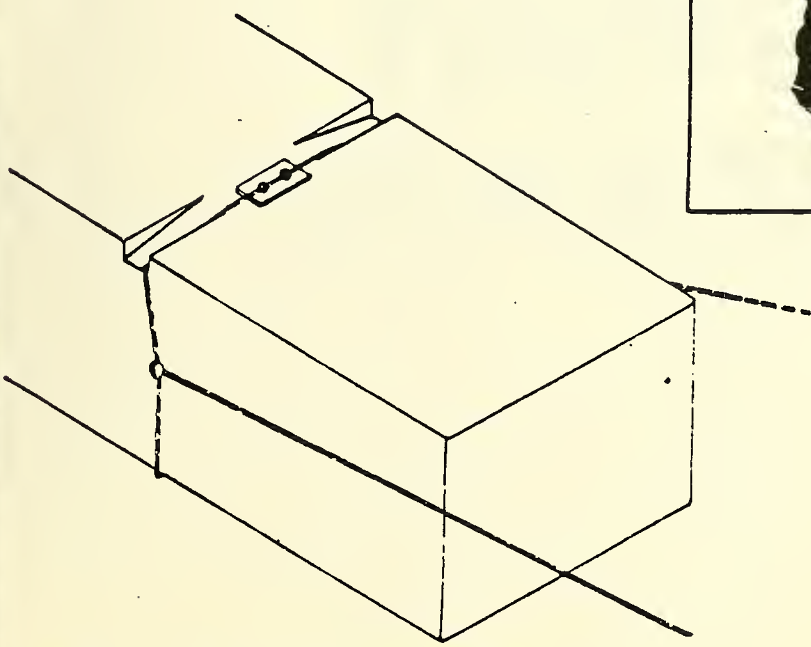
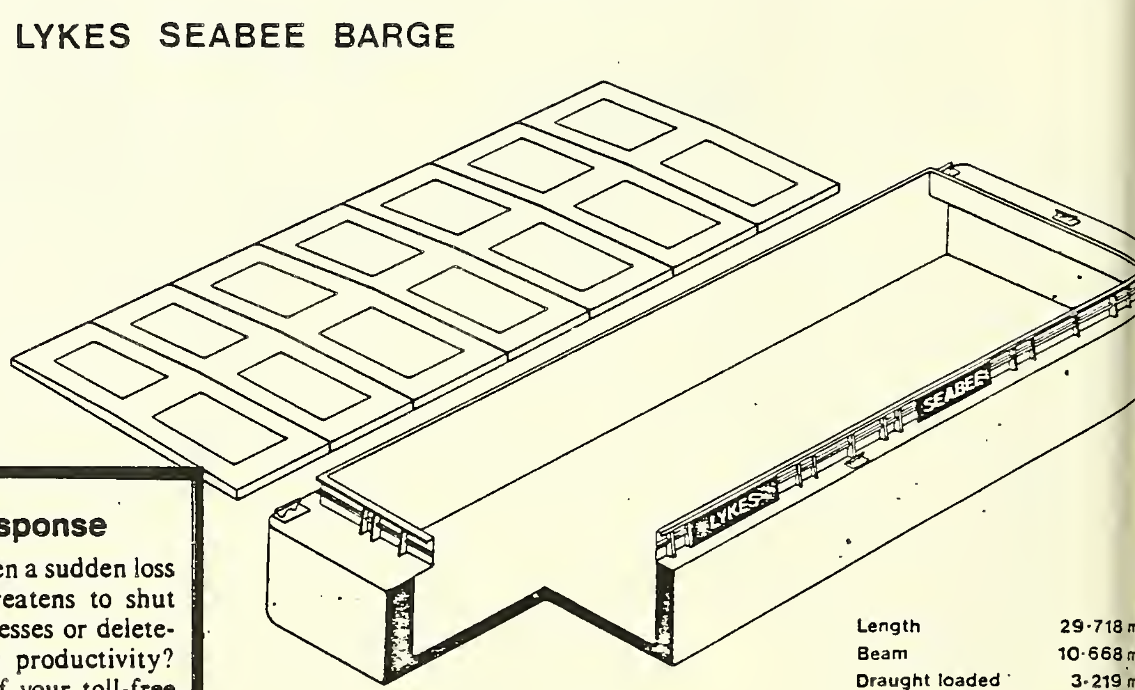


Fig.(1) Wire Loop Towing Method



e barge.

A conditioned response

What do you do when a sudden loss of airconditioning threatens to shut down production processes or deleteriously affect worker productivity? Within 1-1/2 hours of your toll-free call, this company dispatches a truck-mounted airconditioning system to your site from one of nine nationwide service centers. The company says its diesel-powered units typically arrive within 9 hours, ready to deliver 110 tons of cooling at up to 8600 cfm. The self-contained units can operate in remote areas and during total power outages.

Emergency service is $125 per hour with a 24-hour minimum charge; service scheduled more than 7 days in advance (for routine airconditioning system maintenance or scheduled shutdown periods) is $100 per hour with a 120-hour minimum charge. A 12-hour maximum portal-to-portal service charge is added for round-trip driving time to your site. — *Emergency Air Conditioning Co.*

circle 139 on action card

DISTRICT COOLING

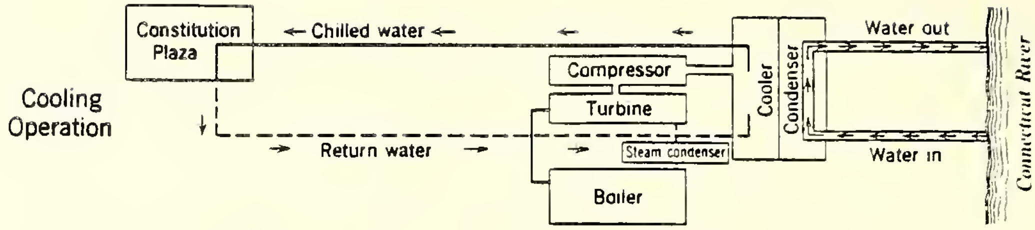


Fig. 18.13 The Connecticut River takes the place of a master cooling tower in the cooling operation of this district heating and cooling service, a departure for the Hartford Gas Company. Its service to the city of Hartford began in 1848 when gas was first distributed.

District Heating and Cooling

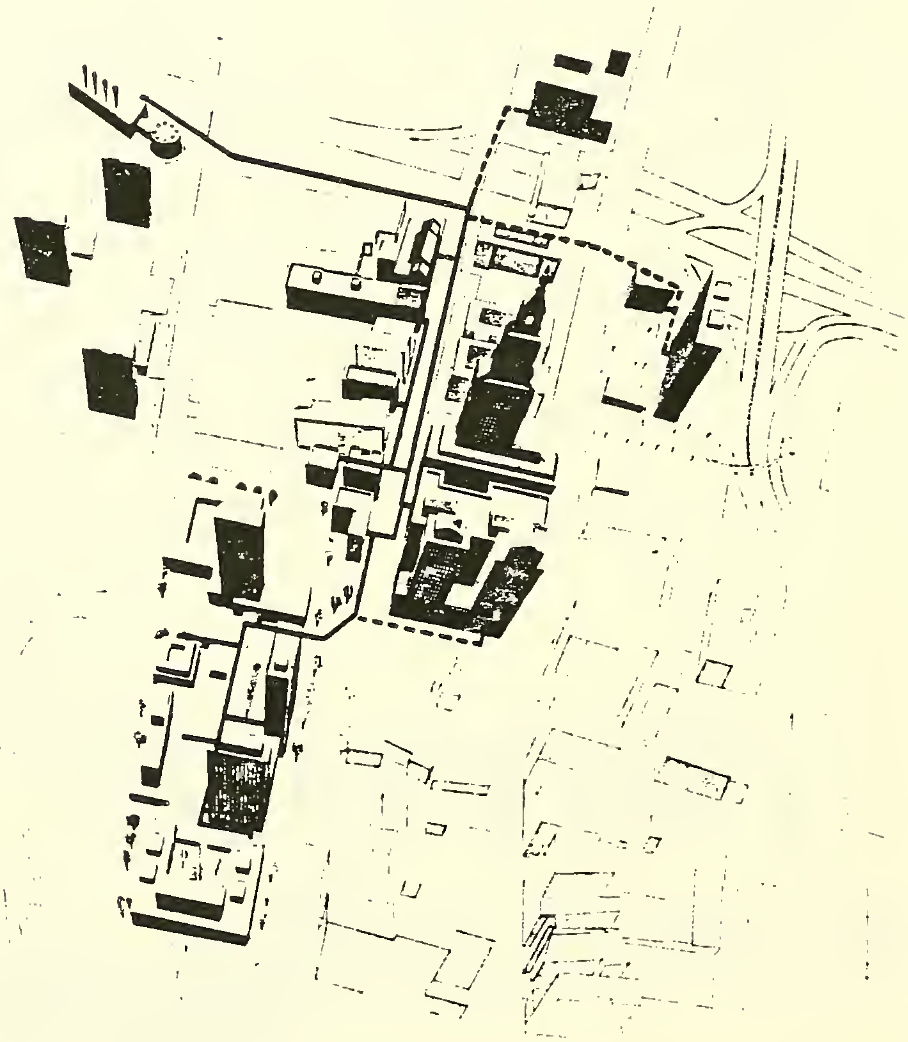


Fig. 18.10 Aerial perspective of downtown Hartford, Connecticut, shows route of pipelines through which cooling and heating service are supplied from a new Hartford Gas Company plant in the southeast section of the city (upper left). The Connecticut River is at the far left and Constitution Plaza, the city's new $40,000,000 redevelopment project is the dark complex of buildings at the lower left. Other dark-shaded structures to be served include the Travelers Insurance Company Building, the city's tallest structure, in the center of the drawing. Gray buildings at upper right (Bushnell Plaza), top (proposed Federal Building), and upper left, (Riverview Apartments), and others connected by dotted lines indicate new and existing construction which will probably be served by extending the pipelines. Lightly shaded buildings are nearby structures offering a potential area of growth for this service.

Because of the seeming impossible task of finding enough storage space on site for any kind of annual storage volume in the central city, it would warrant our investigating the district cooling systems and the volumes of research on community heating proposals. The many district steam systems of our country were given a boost by the hugh demand for absorption cooling which helped to even out the large peaks. As air conditioning became regarded as a necessity, many building complexes (hospitals, universities and airports) installed central refrigeration plants with a separate piping system for the chilled water. Hartford, Connecticut was the first city to install a central chilled water system with a distribution of 6,000 tons through insulated 24" supply pipes.

Often these complexes matched the chilled water system with a hot water system in place of the steam which was the norm for urban use. A normal size piping for steam and the return condensate is 12" and 5", respectively; hot water distribution requires only about 6" pipes but must maintain a higher pressure level.

Today there is increasing interest in development district heating systems based on the ice making heat pumps utilized in ACES (Annual Cycle Energy System). Many variations of cases (Community Annual Storage Energy System) have been proposed with its three storage systems, short term warm water storage, short term cold water storage, and annual heat or ice storage. Community systems capitalize on demand diversity; provide inertia with its thermal storage and includes many sources and sinks (suppliers and users).

Two applications of the HP-ICES System (Heating Pump-Integrated Community Energy System) that have been analyzed for demands and loads are the Market Square complex in Washington, D.C. and the Park Plaza Project in Boston. Three electric screw compressor heat pumps of 555 tons supply the four-pipe distribution system and the Ice Storage Bin of the Pennsylvania Avenue project, while seven ice making heat pumps driven by dual fuel engines supply the heating and air conditioning systems of the Park Plaza Project. In response to Argonnes request for Ice Developments, three proposals utilize ice as a cold sink.

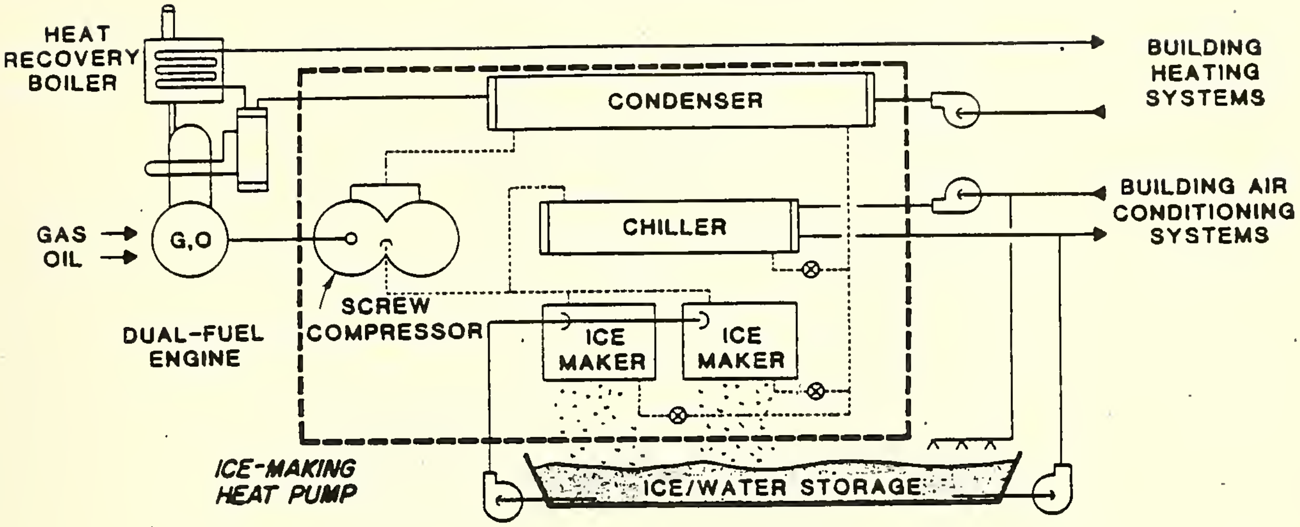


Figure 5.4 Ice-Generating Engine-Driven HP-ICES Schematic

D: Dubin-Bloome Associates PC (New York, New York): This approach employs a community-scale annual cycle energy system (ACES). A central ice-maker heat pump provides heating to a community by extracting heat from water, thereby freezing it. The ice is stored and then melted to provide cooling in the summer. In essence, this system is based on recovery of space heat in summer for use in the winter through a phase change (water-to-ice-to-water) annual storage cycle. H.C. Fischer is a consultant.

F: Franklin Research Center (Philadelphia, Pennsylvania): This concept is a low temperature water distribution system serving user heat pumps. Engine-driven air-source heat pumps and distribution pumps provide the tempered, distribution water. Heat is recovered from the engines in the heating season and is augmented by industrial and power-plant waste heat and by solar energy collected by lakes, rivers, and other surface-water sources. Heat rejection from cooling is used to warm recreational pools and lakes. Werden Associates is a subcontractor and Korman Corporation is a participant.

H: Honeywell Energy Resources Center (Minneapolis, Minnesota): This HP-ICES is a distributed heat pump variation of the annual cycle energy system (ACES) concept. A closed system approach provides a water/ice-slurry distribution loop with a central storage pond for annual storage. An alternative open system approach draws water from the existing potable water supply system and returns an ice slurry or warm water via existing storm sewer systems. In either approach, user ice-maker heat pumps would provide both heating and cooling and a central heat pump would be considered for central distribution fluid preheating. Urban Investment Development Company, and Tolz, King, Duvall, Anderson and Associates Incorporated, are subcontractors; H.C. Fischer is a consultant.

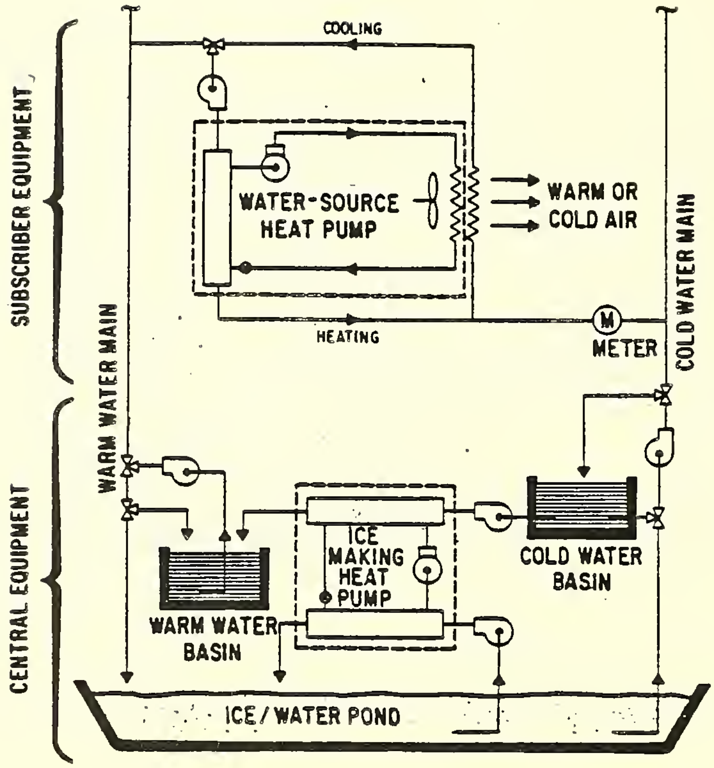


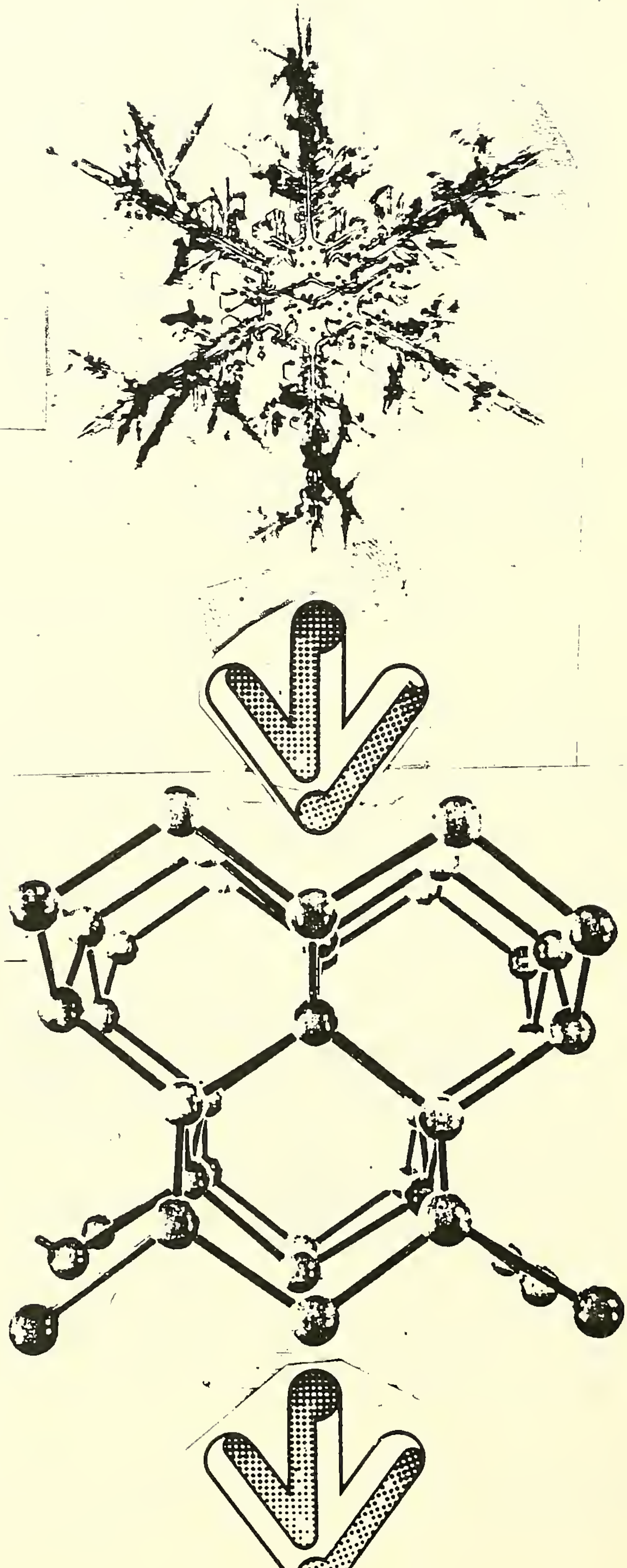
Figure 11.1 CASES Schematic

Long-Term Storage. . A more reasonable long-term storage medium would be ice. As with ACES, an ice-storage CASES would use heat pumps to produce ice during the winter, and use the ice to provide air conditioning in the summer. Any excess ice could be melted by water warmed by circulation through cooling towers or spray ponds during periods of above-freezing temperatures. As with ACES, the ice storage would be sized to meet the annual cooling demand. For example, a neighborhood or community of 5,000 in a climate like Boston's would require an ice storage volume of about 5.7 million cubic feet, equal to a pond 50 feet deep with a surface area of 2.5 acres (Powell).

The efficiency of CASES would be quite high because the system's heat pumps could be designed to operate on a constant temperature water heat source. The annual COP of the system would be 4 to 5, while in the summer, it would be as high as 15. Cost of the system, per household, would vary depending upon climate, but would be less than that of an ACES, perhaps on the order of $8,000 to $16,000. This is about twice as expensive as conventional heat pump systems, however, because the system would be community-based, rather than individual, and financing arrangements could be very flexible. For example, payment might be through a monthly heating bill.

At the present time, CASES and other similar, innovative community-scale heating systems are only the subjects of paper studies and computer simulations. None have actually been constructed.

NATURE'S ICE



Since most of the natural ice found in Boston would be a form of salt water (sea water and salted snow and ice) it would warrant our investigating the unique characteristics of this medium. The primary salt in the ocean is sodium chloride, NaCL, while that thrown on the ice and snow on city streets is calcium chloride, $CaCl^{2}$. Generally speaking as the salinity of the water increases, its freezing point lowers. The bulk of our experience with salt water derives from:

1. Experience in artic regions - the Army and Navy have done many experiments on the strength, growth rates and thermal, electrical and acoustical properties of sea ice as they often use ice as a structural material in artic regions.

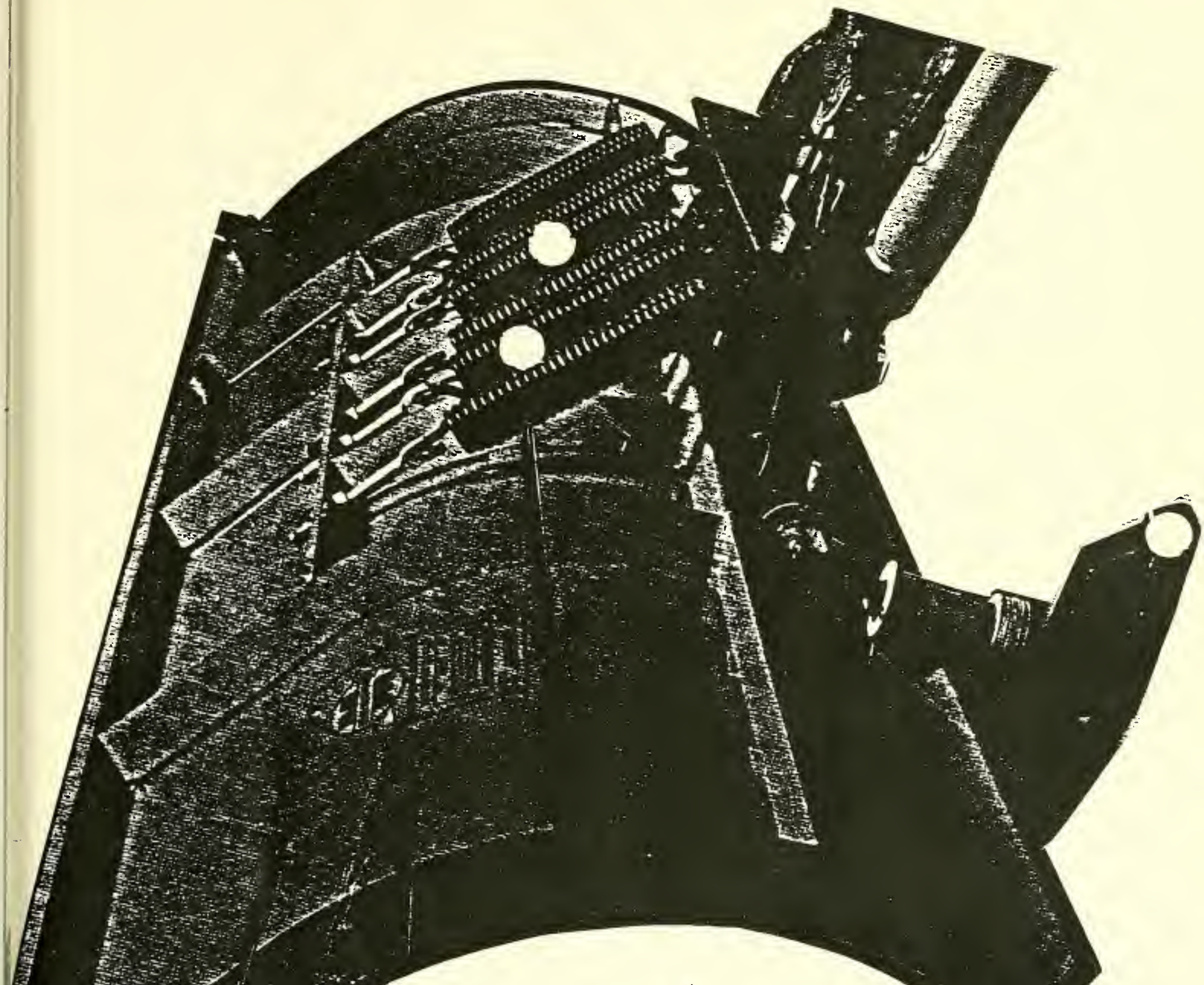
2. Marine salt water freezes on fishing vessels. Ships are often equipped with stainless steel salt water refrigeration systems to cut down on the load and fuel needed to get to sea and to better preserve the salt water catch.

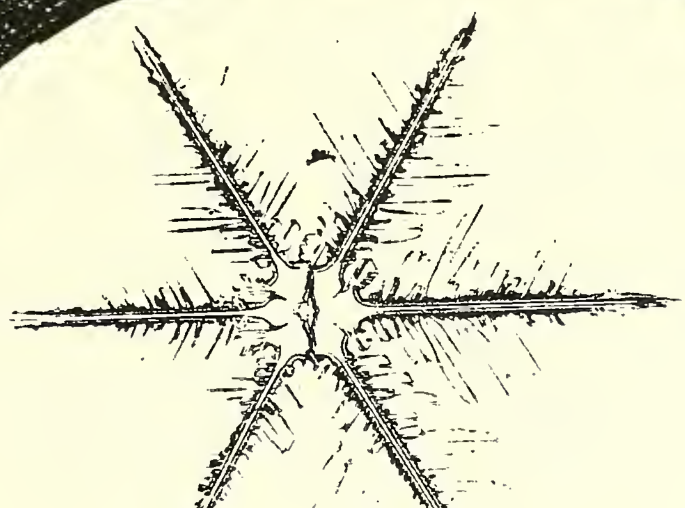
3. Salt water cooling towers and condensers for nuclear and power plant waste heat - as the waste heat often exceeds environmental standards for dumping into the ocean and fresh water supplies are inadequate, salt water cooling towers and condensers are resorted to. Some of the more prevelent materials used to resist corrosion are stainless steel, nickel, copper, titanium, high silicon bronze, epoxy coated carbon steel and chromate impregnated wood, while chlorine and biocides are added to the water to prevent biological growth.

4. Brine lines to cold storage warehouses and ice skating rinks - for years brine has been moved in black iron pipes and today in plastic ones. A small amount of lime and calcium oxide will keep these lines clear.

5. Desalination of seawater by freezing methods - many variations of vacuum and butane freezing resalination have been experimented with. Abstractly freezing requires only 144 BTU's compared to the 1,000 BTU's required for the distillation process; however, the problem of the precipitated brine ____________ or becoming entrapped has still to be satisfactorily to be resolved.

6. Solar ponds - (for solar collection and storage). The most famous natural solar pond is the Dead Sea which has long utilized its unique characteristics as a heat sink. However, solar pond can be artificially created and the state of Ohio is covered with them; the University of Ohio is entirely heated via solar ponds. When a still body of water is saturated with a high content of salt, layers or thermoclines of heat become very distinct and the heat becomes entrapped in the saltier bottom layer. By pumping the hot brine to a heat exchanger, much space heating can be obtained.





375 (×45)

Heat Sink Capacity of a Snow Dump Site

John R. Feick and Robert Goulet
Environmental Scientists, Inc.
and St. Anselm's College,
Manchester, NH 03102

Rationale:

A heat sink can be a valuable economic benefit if properly managed. The snow residues of a city, when plowed and stacked or trucked away, represent a formidable heat-absorbing capacity.

Air conditioning and refrigeration engineers have long used well water as a natural heat sink to cool the condenser coils of refrigeration equipment. Our objective has been to determine the economic feasibility of using snow in the same manner.

In our study, we have attempted to answer three questions as follows:

1. How much snow might be available, when compared with the requirements of a major commercial building?
2. How can snow be economically preserved for midsummer use?
3. What proportion of a building's air conditioning budget could be saved by a well-managed snow cooled air conditioning system?

The amount of snow available and being moved in the Manchester, NH, area was calculated for eleven city parking lots, the municipal airport, a large shopping mall, and the regional Postal Service center. The original plan was to survey the mass of the actual snow dump sites after snow removal.

Since snowfall in our area this past winter was unusually light, we have used US Army Corps of Engineers data for the average snow accumulation on the ground as of March 15 as a basis for our estimates. The available snow far exceeds the cooling needs of our model, the US Postal Service building, but snow from the adjacent Postal Service parking lots would supply only 46% of the building's requirements.

Snow insulation and preservation were tested using a method that could be adapted to large scale commercial use.

A four inch thick mat of foam plastic with an insulation value of R11, covered on the top surface with reflectorized plastic, was used to cover part of a snow pile leveled off at six feet in height. The melt rate of the ten by ten foot covered area of the snowpile was compared with an equal uncovered area. Our data show an average melt rate of twenty five inches per week for the uncovered control and five inches per week for the mat covered area of the snowpile.

Having available large quantities of snow for air conditioning purposes during the summer does not eliminate all air conditioning costs. Pumping a refrigerant and circulating cooled air would still be necessary. The Postal Service building expends approximately $8095 per year on air conditioning; snow use would save approximately $4562.

Our study has not considered the costs of installation and management, but the data suggest that a snow cooled system should, at present, be viewed as a possible alternative to reduce electric power consumption rather than a way to dramatically reduce costs.

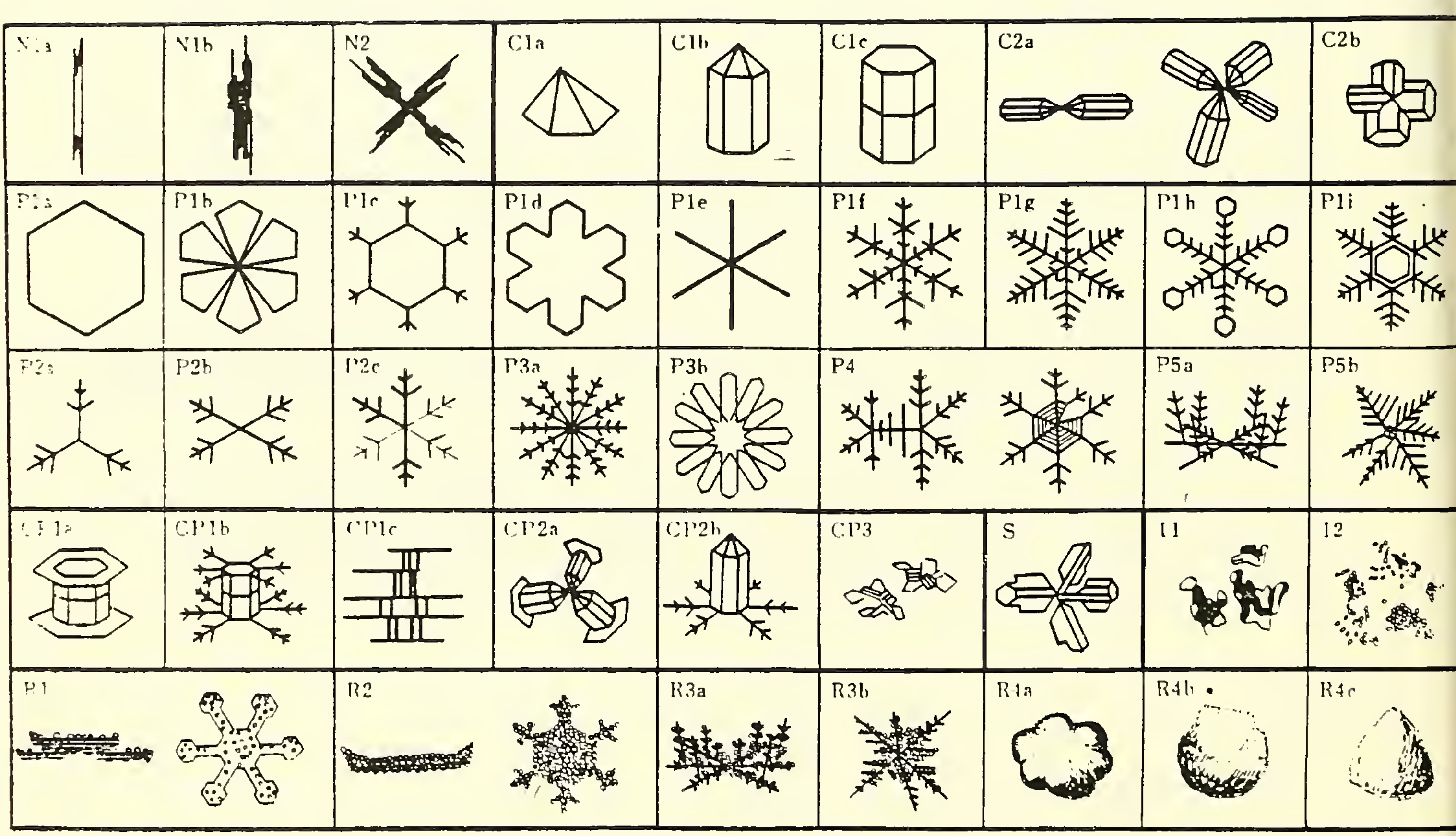
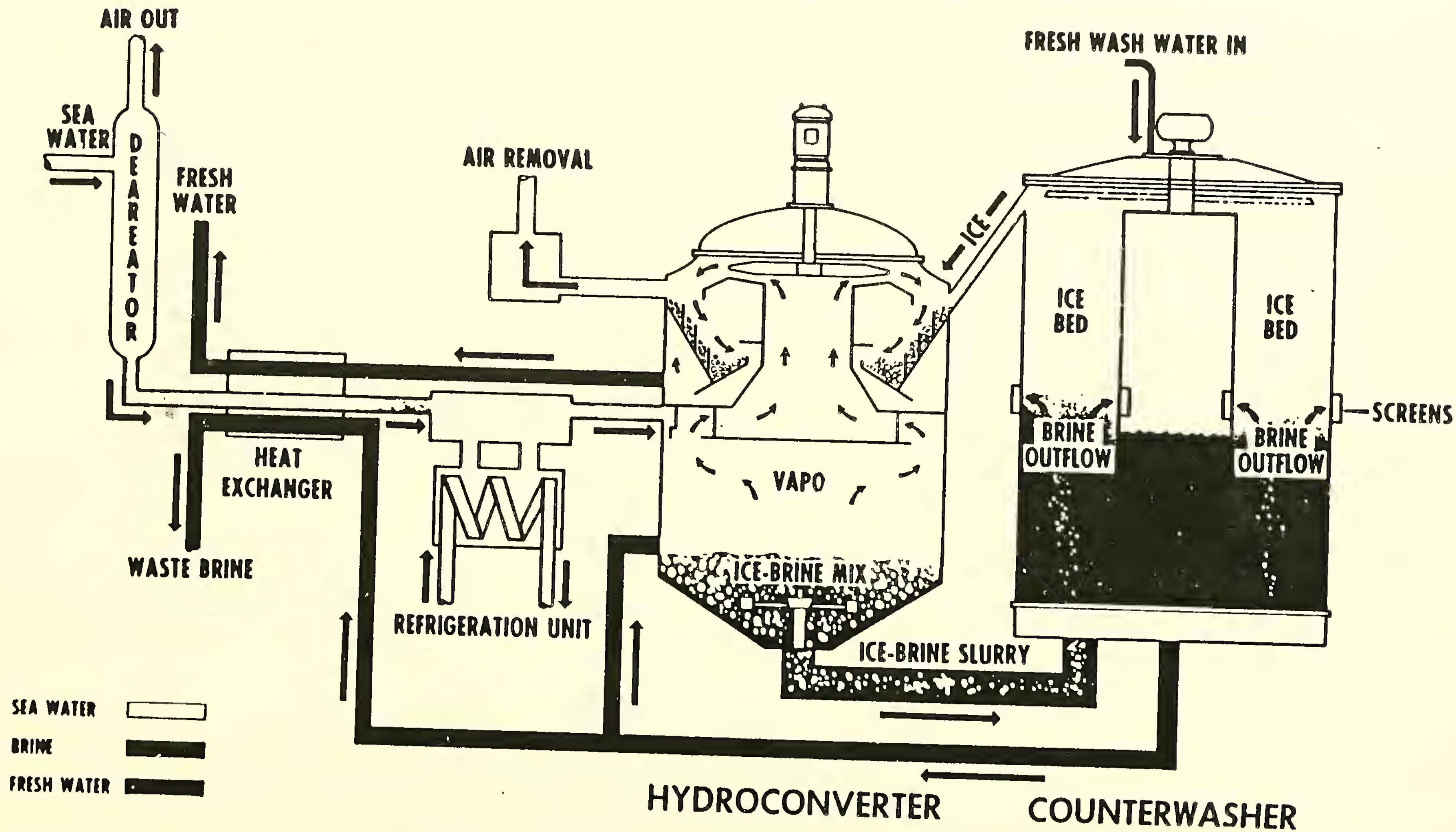


FIG. 197. General classification of snow crystals, sketches.

Vacuum freezing vapour compression process



DESALINATION BY FREEZING WATER

The inherent energy requirement of the freeze separation method for the conversion of saline water is much lower than that required for the distillation process. 144 BTUs per pound is required for freezing water while 1,000 BTUs is necessary to vaporize it. However because the brine tends to cling to the pure ice, some of the generated product must be utilized in a washing process. The vacuum freezing vapor compression system, which employs a cylindrical column has the most promise for moderate size conversion plants. In addition to its energy advantage, the freeze method offers advantages in using lower-cost materials of construction because of less corrosion problems at the lower temperatures. Because of the high concentration of salts contributing to formation of scale which is found in many brackish waters, the freezing process has more potential in the arid southwestern United States. For sea coast operation, a low temperature sea water feed would offer advantage although some protection against freezeup might be necessary. The cost of desalting water by freezing might be lowered by recovery of the by product elements such as magnesium, bromine, flourine and salt. In dual purpose plants for production of water and electricity, the brine could produce chlorine and hydrogenchloride, while the utilization of the ice for cooling and refrigeration could produce even greater savings.

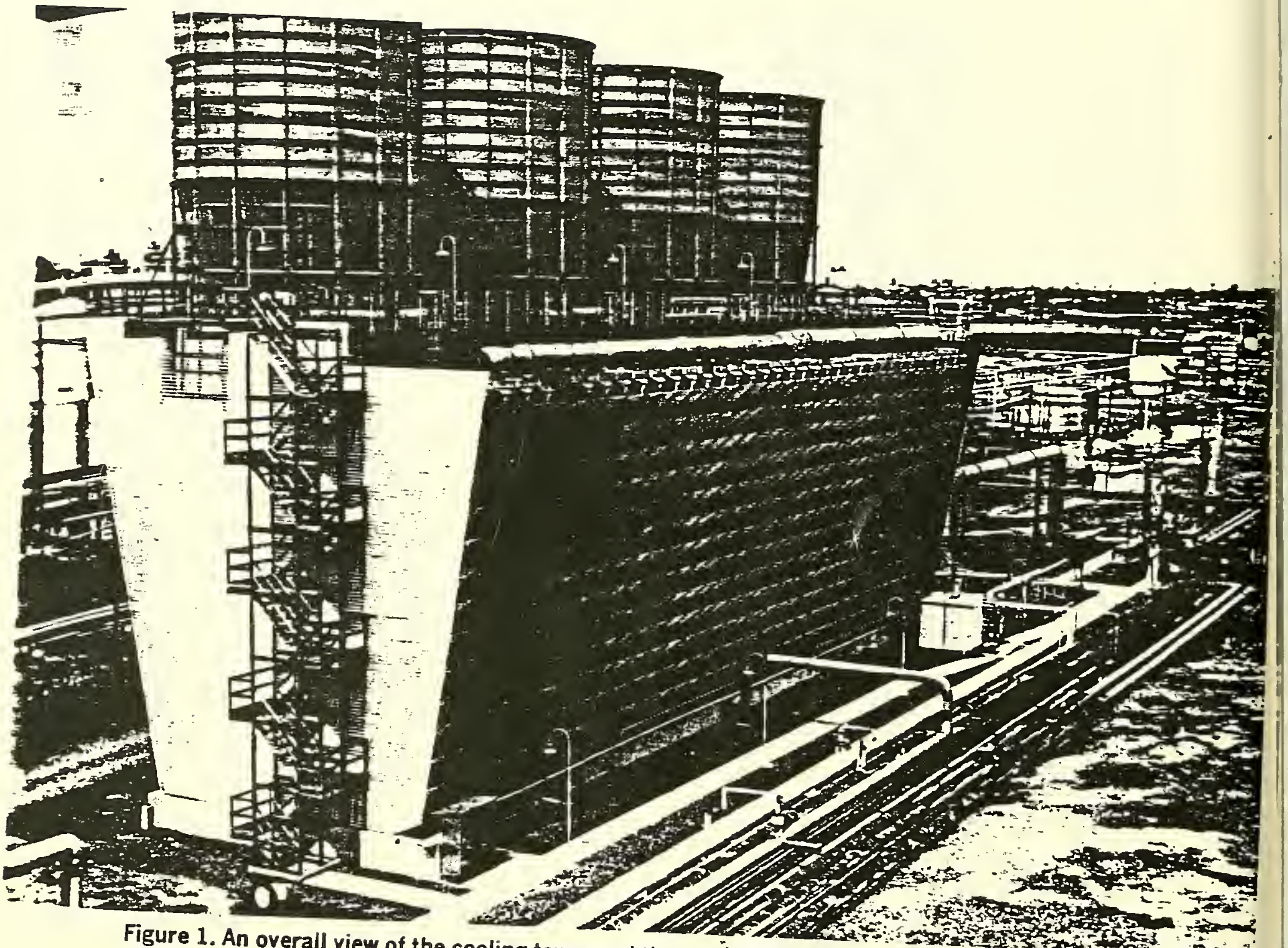


Figure 1. An overall view of the cooling tower and the surrounding equipment. This view is looking to the nor
west.

ANNUAL HEAT TRANSFER ISSUE:

Salt Water Cooling Tower

Construction materials must be carefully selected for salt water towers if these units are
withstand the effects of corrosion.

THERMAL STORAGE VIA PHASE CHANGE MATERIALS

There are alternatives to using water as the phase change material and latent heat can be stored in numerous materials including many of the salt mixtures. The main advantage of using a salt mixture is the elevation of the 32° F freezing point of water which allows more efficient evaporator temperatures. Four cold storage proposals utilizing phase change materials include two MIT thesises:

1) "Off Peak Cooling Using Phase Change Material" by Charles Benton, Master of Architecture '79

2) "Off Peak Cooling of Building Core Zones" by Charles Toups - Master Mechanical Engineering '82

3) The University of Delaware's Project to Commercialize Phase Change Materials; and

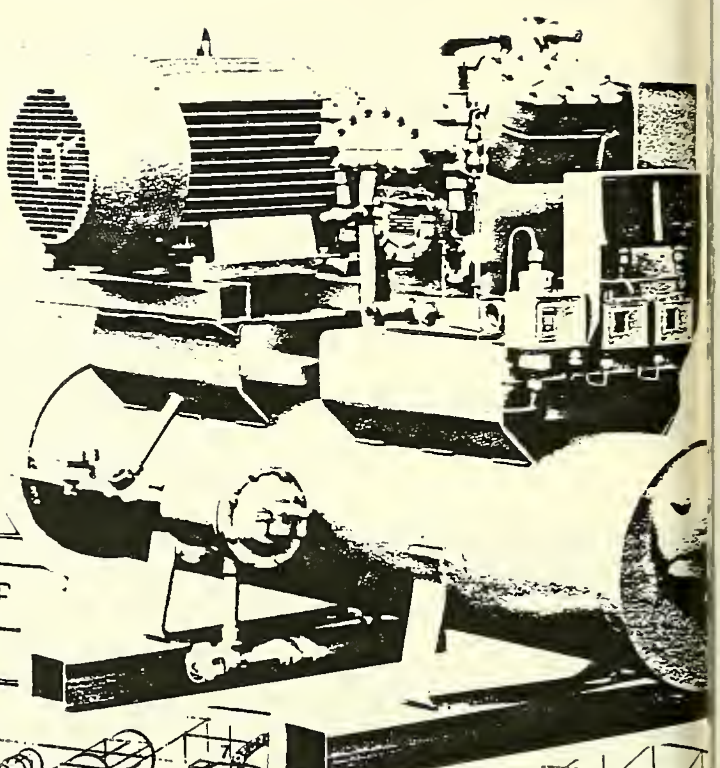
4) The C10 Product of the Calor Alternative Energy Company.

The University of Delaware developed a sodium sulphate decahydrate based salt hydrate mixture with a phase change at 45°-57° F. The transition point of the mixture has been adjusted by the addition of salts such as sodium chloride, ammonium chloride and potassium chloride and stabilized by the addition of a gelling agent. It is packaged in 1.25" diameter plastic tubes (used in the food processing industry) and spaced 3" o.c. in boxes. 1 cu. ft. of storage bin supplies 2250 BTUs of thermal storage.

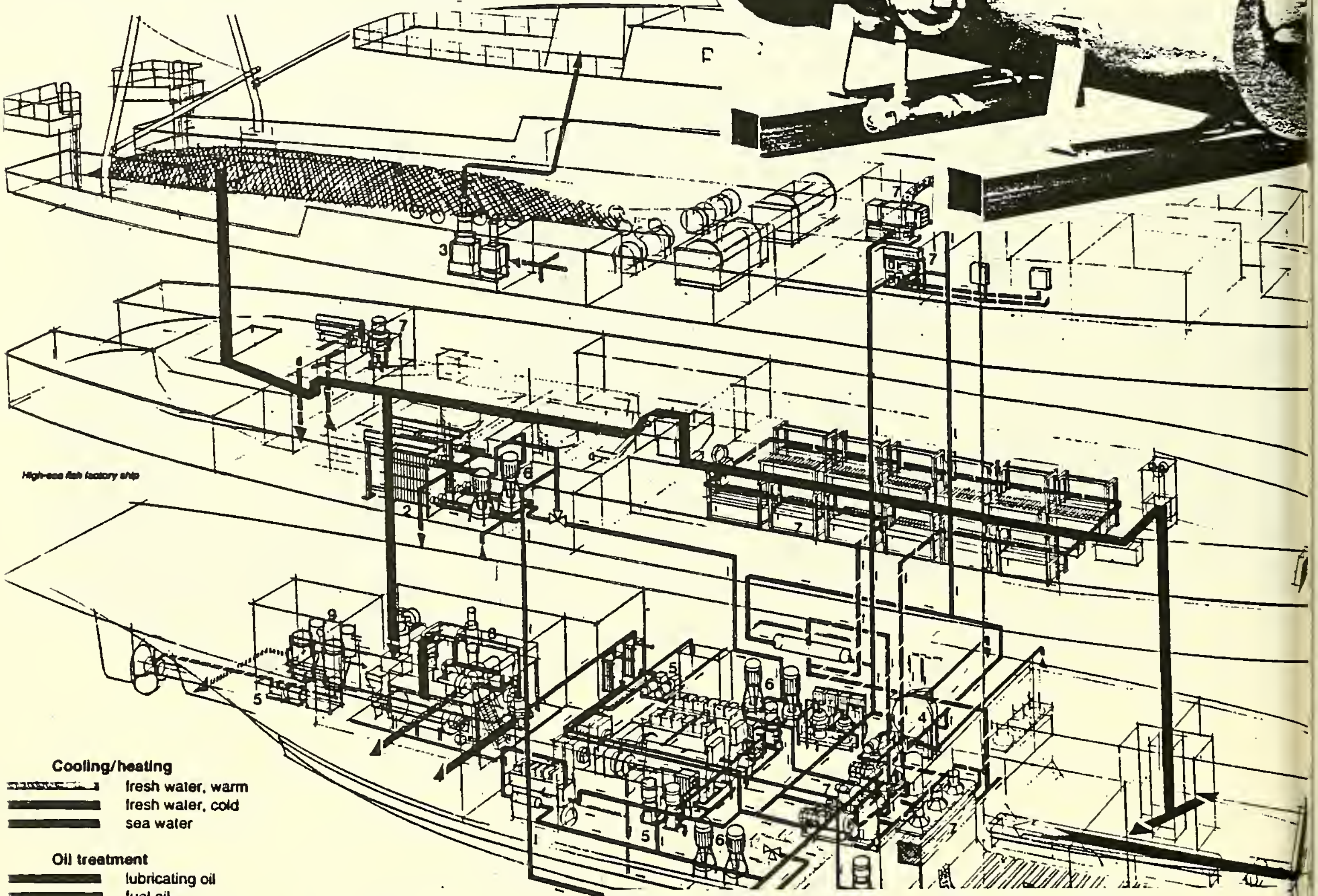
Charles Toups proposed a PCM of sodium sulfate decahydrate $N_4\ SO_4\ 10H_2O$ with ammonium chloride borax and fumed silica additives enclosed in thin heat sealed bags on top of the tiles in the ceiling suspension grid with the major phase change occuring at 18°-24°C.

Calor's 2" diameter and 4' long polypropylene tubes have a transformation temperature of 50° F and an average storage capacity of 505 BTUs. Two of the more common problems associated with the salt hydarate solutions are the decreasing of the storage capacity with subsequent uses and the triggering required for cooling which can lead to super cooling caused by the disparities between densification.

Marine refrigeration utilities an adaptation and modification of cooling on land. More care must be used in choosing a refrigerant because of the confined quarters in case of accident and salt water is often substituted for sweet water which has different thermal properties and corrosion effects. Many reefers, gas carriers, chemical tankers, container ships, fishing trawlers and vessels are fitted with special refrigeration equipment to function in salt air and water conditions.



Marine Refrigeration



FRESH WATER ICE

- Is easy to distribute by air blowing systems blowing the ice in hoses
- Can be stored at higher room temperatures
- The risk of the ice freezing together into bigger lumps is minimized
- Suitable for storing for longer periods
- Requires increased fresh water capacity (tanks or generators)
- Ensures a fixed melting temperature
- Is homogeneous, solid, and hard

SEA WATER ICE

- Requires lower operating temperatures which gives increased sub-cooling of the ice
- Has to be stored at lower room temperatures
- Rather soft and flexible ice
- The low temperature brine (salt water) leaves the ice first and thus gives a faster cooling of the fish
- No shortage of »raw material«
- Reduced spoilage rate overcomes the possible disadvantage of partial freezing and salt uptake
- Filleting fish stored in sea water ice gives a normal yield

POSSIBILITIES
OPPORTUNITIES
FOR BOSTON

Now that we have compared the various means of refrigeration and space cooling, historic and contemporary, natural energy methods to intensive users of fossil fuels, individual room units to district cooling systems; it remains for us to adapt the newer technologies to the central core of Boston. Although the exchange and transportation buildings save considerable expense by leveling their cooling loads in the summer, there is yet no building complex which is actually eliminating mechanical cooling and refrigeration.

There are many physical constraints and technical difficulties to be addressed before adapting the newer systems to central Boston; the enormous volumes of storage, the mildness of some of our winters, and the extra load on condensers and compressors to lower water below 32°.

The adjacent chart lists development proposals for Boston and indicates the specific type of cooling technique which should be explored and investigated in eliminating tonage and costs.

Development	Manufacture	Storage	Distribution
Hyde Park	natural snow	Quarry	melted snow chilled water pipes
Navy Yard	heat pipes	undergd. tanks	old steam lines
North Station	heat pipes	undergd. mud	heat exchanger
Ft. Pt. Channel	snow box	Boston Edison Site	chilled water pipes
Copley Place	Ice Islånd	enterprise zone site	tractor/trailer 40' container
Theatre/Cable(31) District	heat pump	subway tunnel	Heat Exchanger Pump
Dewey Sq. 1 P.O. Sq.	chillers @ nite Screw Compressor	exist tanks	heat exchanger cold air ducts
Mass. General Financial Dis	ice maker	floating Boston Harbor	pneumatic hose flaked ice to condensers
E. Boston Bird Island	ice builder (coils)	underground air field	melt to condensers
Enterprise Zone	snow gun	on site	heat exchanger
Lafayette Place	Ice Island	Enterprise Zone	Tractor Trailer
Columbia Point	Snow Box	Vacant High Rise	Exist. Steam Lines
Waterfront, Rowes, Aquarium, Harbor Towers	Ice Island	S. Boston	Tug Boat
D6; D10	Ice Builder	Old Subways	Heat Exchanger

Ice Storage System Design

All ice storage systems, whether full or partial, involve the selection and installation of the basic components of a mechanical refrigeration system: evaporator (ice builder), compressor, condenser, and refrigerant feed device. This section will discuss the various types of compressors, condensers, and refrigerant feed devices that are available, and which of these choices are preferred for application with ice builders. The key selection parameters are outlined, as are the design considerations required for successful installation and operation of an ice builder system.

COMPRESSORS

Positive displacement compressors such as the reciprocating and rotary screw types will best provide the low and varying evaporator temperatures that are characteristic of ice builder operation. During the ice building process, evaporator temperature decreases (typically from about 25°F to 10°F) due to the increasing resistance to heat transfer caused by the accumulating ice.

Reciprocating compressors are available in single units up to a maximum of about 200 HP. These units will be best suited for small to medium ice builder systems where they can be matched on a one-for-one basis with an ice builder. The largest factory-assembled ice builders require a maximum compressor size of about 150 HP.

For larger installations where capacity requirements would necessitate a multiplicity of reciprocating units, the rotary screw compressor would be the logical choice. These are available in unit sizes up to about 1500 HP.

The centrifugal or turbo compressor, most commonly used on medium and large water chilling systems for air conditioning, is basically a constant head machine and does not have the ability to perform efficiently over the rather wide range of evaporator temperatures required by the ice builder systems.

Compressor selection is based on three parameters: required capacity (usually expressed in tons), evaporator temperature, and condensing temperature. The required capacity is determined by dividing the amount of thermal storage (in ton-hours) by the number of hours that the refrigeration system is in operation.

$$\frac{\text{Storage Capacity (ton-hours)}}{\text{Operating Time (hours)}} = \text{Required Compressor Capacity (tons)}$$

Evaporator temperature is determined by the number of hours available to form ice in the ice builder, and is a function of the geometry of the ice builder coil. See Bulletin S140/1-0, B.A.C. Ice Chillers™, for specific data on the relationship between build time and evaporator temperature.

The choice of system design condensing temperature is determined from the design ambient wet bulb or dry bulb temperature and the type of condensing equipment. Therefore, a knowledge of the specific ambient conditions at the jobsite and a preliminary selection of the method of condensing is necessary.

CONDENSING EQUIPMENT

The heat rejection function of an ice storage system can be handled by any of the three basic types of refrigerant condensers; air cooled, water-cooled, or evaporative. Each type has advantages and disadvantages which should be evaluated against the specific design criteria in order to determine the best choice for each project.

Air-cooled condensers

An air-cooled condenser removes heat from a refrigerant and condenses it by blowing air over an extended surface coil through which the refrigerant vapor is circulated. The latent heat of the refrigerant is removed by sensibly heating the air, so the condenser capacity is determined by the ambient dry bulb temperature.

The primary advantage of air-cooled condensers is their simplicity, since they consist of just a coil, fan system, and enclosure. A fundamental disadvantage, however, is their inefficiency; a large volume of air flow and consequently high fan horsepower is required because the air-cooled condenser utilizes only the sensible heat pickup of the air. Additionally, the large air volume requires a correspondingly large condenser plan area.

In general, air-cooled condensers must be selected for higher condensing temperatures than condensing methods that utilize evaporative cooling and operate against the ambient wet bulb temperature. Design dry bulb temperatures are normally 15°F to 25°F higher than design wet bulb temperature, so condensing temperatures for air-cooled condensers will be at least that much higher than condensing temperatures using evaporative cooling, resulting in increased compressor horsepower.

Water-cooled condenser with cooling tower

A water-cooled condenser with a cooling tower rejects heat from a refrigeration system in two steps; the refrigerant is condensed by the water flow in the condenser, and then the heat is rejected to the atmosphere as the water is cooled in the cooling tower. Since this arrangement utilizes the evaporative cooling principle (in the cooling tower), it rejects heat in a relatively efficient manner. The total energy required to reject the heat (pump horsepower plus cooling tower fan horsepower) is less than for air-cooled condensers at the same condensing temperature. The equipment requires less space, too, and generally will cost less.

The water-cooled condenser/cooling tower approach is often used to minimize condensing temperature and, hence, compressor horsepower. Since the capacity of the system is a function of ambient wet bulb temperature, condensing temperatures 15°F to 25°F lower than air-cooled condensing temperatures are possible.

Water consumption and treatment are occasionally cited as a disadvantage of this method of heat rejection, but energy considerations usually have greater impact on the economic analysis of the system. Also, the water-cooled condenser/cooling tower approach can be the best solution on installations where the heat rejection equipment is remote from the compression equipment, and local codes limit or prohibit the installation of refrigerant lines in or near occupied spaces.

Evaporative condensers

The evaporative condenser combines a water-cooled condenser and cooling tower in one piece of equipment. It eliminates the sensible heat transfer step of the condenser water, which permits a condensing temperature substantially closer to design wet bulb temperature, and consequently, minimum compressor horsepower. Condensing temperatures within 15°F of design wet bulb are practical and economical, resulting in compressor horsepower savings of 10% or more over water-cooled condenser/cooling tower systems, and more than 30% over air-cooled systems. Fan horsepower is comparable to water-cooled condenser/cooling tower systems, and is about one-third that of an equivalent air-cooled condenser.

Since the flow rate of water in an evaporative condenser need only be enough to thoroughly wet the condensing coil, water flow rate and head are reduced, and pumping horsepower is only about 25% of that required by a water-cooled condenser/cooling tower system.

The evaporative condenser combines the cooling tower, condenser surface, water circulating pump, and water piping in one assembled unit, thereby eliminating the cost of shipping, handling, and installing separate components. And since the evaporative condenser utilizes the efficiency of evaporative cooling, less heat transfer surface, fewer fans, and fewer fan motors are required, resulting in material cost savings of 30 to 50% over a comparable air-cooled condenser.

By combining the condensing coil and cooling tower in one unit, the evaporative condenser saves valuable space. It also requires about 50% of the plan area of a comparable sized air-cooled condenser, since it requires only about one-fourth of the airflow.

Considering the lower first cost, space savings, and especially the minimum energy requirements, evaporative condensers should be the best choice in condensing equipment for most ice builder systems. Detailed selection and application data on evaporative condensers are available from your local B.A.C. representative.

REFRIGERANTS AND REFRIGERANT FEED METHODS

Three types of liquid refrigerant feed can be applied to ice storage systems: direct expansion (using a thermal expansion valve), gravity flooded, and liquid recirculation. In theory, all of these methods can be applied to systems using any halocarbon refrigerant, or ammonia (R-717). However, the refrigerants most commonly used on ice builder systems are ammonia and R-22 because they are relatively inexpensive, readily available, and their thermodynamic properties result in minimal installed cost compared to other refrigerants. Measured against these criteria, ammonia is preferable to R-22. However, due to its relatively high toxicity, ammonia is generally limited to applications where the system can be isolated.

Direct Expansion (Thermal Expansion Valve)

Direct expansion refrigerant feed is best suited to R-22 applications where a single ice builder is matched with a single compressor. It is the least efficient of the three types of feeds since 15 to 20 percent of the coil surface is used to provide superheat for operation of the thermal expansion valve and this superheating surface is ineffective for building ice. Therefore, some adjustment must be made in the selection of the ice builder or in the operation of the system. There are three possibilities in this regard: select a larger ice builder; build ice over a longer period of time; or select the compressor for a lower suction temperature. The most logical choice is to select the compressor for a lower suction temperature, since the penalty is only on the order of 5°F. A typical thermal expansion valve feed arrangement is shown in Figure 12.

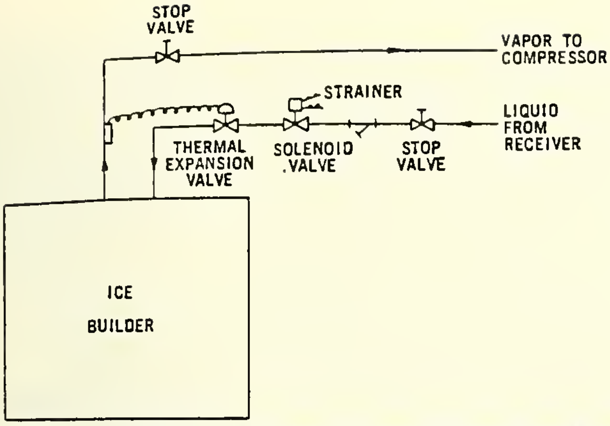


FIGURE 12: Refrigerant Feed System: Thermal Expansion Valve (DX)

Despite its performance limitations, direct expansion liquid feed is favored by many system designers because of its familiarity, low cost, and simplicity with regard to oil return (see page 19). Direct expansion feed controls can be furnished by B.A.C. with the ice builder; if furnished by others, consult ASHRAE Handbook, 1980 Systems Volume, Chapter 26, System Practices for Halocarbon Refrigerants, for detailed design recommendations.

Gravity Flooded

A gravity flooded refrigerant feed arrangement (Figure 13) permits wetting of the entire internal surface of the ice builder coils by overfeeding refrigerant liquid. The quantity of liquid fed to the coils is many times the quantity of refrigerant that is evaporated, ensuring a thoroughly wetted internal coil surface. This results in full utilization of the coil surface for forming ice, because the superheat penalty that is characteristic of direct expansion is eliminated.

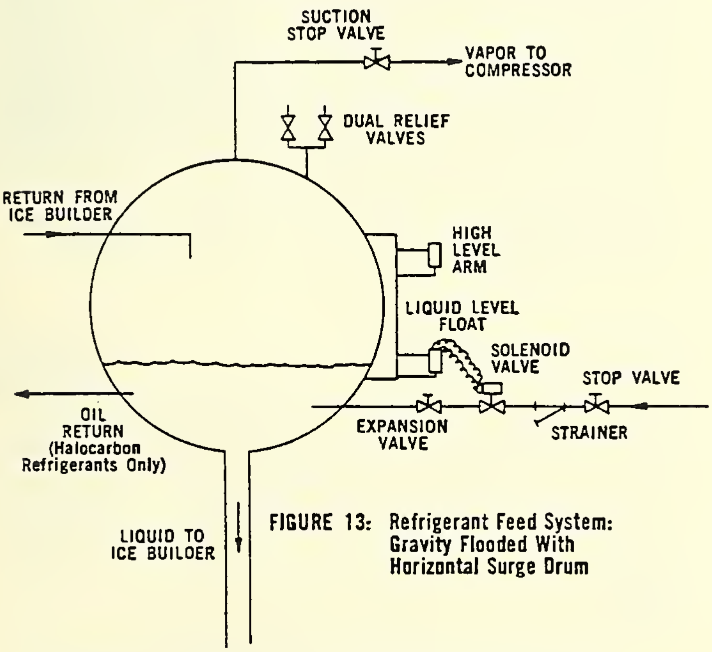


FIGURE 13: Refrigerant Feed System: Gravity Flooded With Horizontal Surge Drum

As shown in Figure 13, the gravity flooded system consists of a horizontal surge drum mounted above the ice builder coils, a float switch or pilot-operated low pressure float to maintain liquid level in the surge drum, and a vertical header at the bottom of the surge drum to carry liquid refrigerant to the coil inlet. A suction line from the coil outlet connection returns a refrigerant-vapor mixture to the surge drum. Here the two phases are separated, thus preventing liquid from returning to the compressor. A suction line from the top of the surge drum returns the vapor to the compressor; the returned liquid remains in the surge drum, and is available for recirculation to the ice builder coils.

Any number of gravity flooded ice builders may be connected in parallel on a central compression system. However, the large refrigerant charge for this feeding system plus the repetitive cost of surge drums, float valves, solenoids, etc., makes this feed system impractical where multiple ice builders are involved in a system. Surge drums with the necessary control valves are available from B.A.C. with the ice builder. If this equipment is to be furnished by others, consult ASHRAE Handbook, 1980 Systems Volume, Chapter 26, System Practices for Halocarbon Refrigerants, or Chapter 27, System Practices for Ammonia, for data on the design of surge drums and controls for gravity flooded evaporators.

Liquid Recirculation

Where a number of ice builders are connected to a common compression system, the liquid recirculating system is ideal for feeding refrigerant to the evaporator coils. This system consists of a vertical or horizontal accumulator equipped with a low pressure float control or float switch, and a refrigerant recirculating pump. See Figure 14. All of the refrigerant required by the ice builders is fed into the accumulator and the liquid level is maintained by the float.

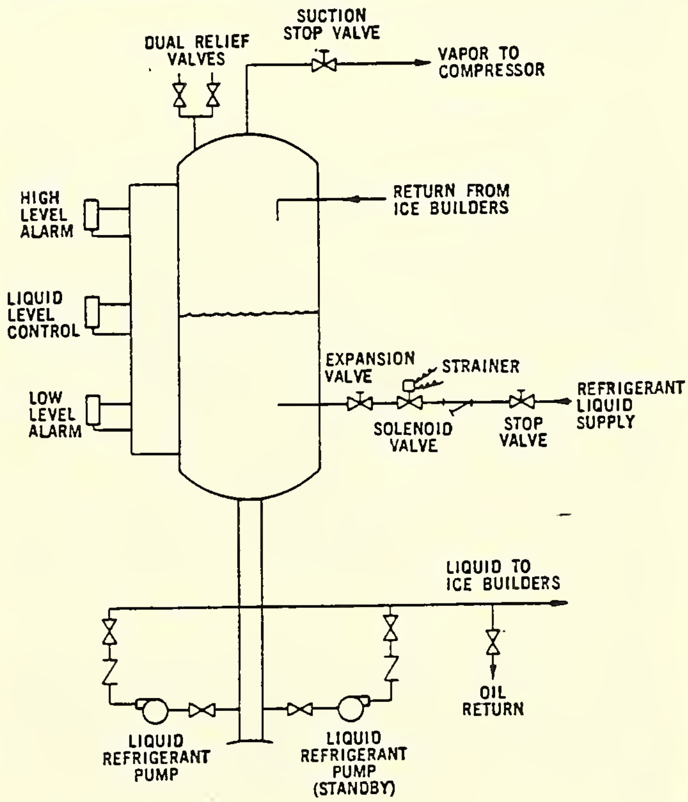


FIGURE 14: Refrigerant Feed System Pump Recirculation Package With Accumulator

A refrigerant pump is used to circulate the liquid refrigerant from the accumulator to the ice builder coils. The liquid-vapor mixture from the coils is returned to the accumulator where the liquid drops out and the vapor proceeds to the compressor through the suction connection. Only one accumulator, one pump, and one set of control valves is required for handling any number of ice builders. This is a distinct advantage both from an operation and cost standpoint over the gravity flooded systems where surge drums and controls are required on each ice builder.

The refrigerant recirculation rate must be sufficient to overfeed the ice builder coils and to permit metering the refrigerant to each circuit within each coil. Generally with the halocarbon refrigerants (R-12, R-22, or R-502) a recirculating rate of 2 or 3 to 1 is sufficient.

The ice builder coils may be either up fed or down fed; down feeding is preferred where a minimum refrigerant charge is desirable. If down fed, a distributor or orifice must be used to distribute the refrigerant to each coil circuit. If up fed, distributors or orifices are unnecessary since the head of refrigerant in the coil will automatically provide even distribution.

A liquid recirculating package, consisting of accumulator, pump, and necessary controls can be furnished by B.A.C. to meet any specific system design. However, if this equipment is to be furnished by others, it is recommended that the designer consult the ASHRAE Handbook, 1980 Systems Volume, Chapter 25, Liquid Overfeed Systems, and Chapter 26, System Practices for Halocarbon Refrigerants, or Chapter 27, System Practices for Ammonia, for specific recommendations on the design of liquid recirculating systems.

REFRIGERANT PIPING

This section addresses the various factors that must be taken into consideration when designing the connecting refrigerant piping of an ice builder system. It is not within the scope of this guide to provide design piping for all possible types, locations, and arrangements of the system components. These design data are well covered in ASHRAE Handbook of Fundamentals, Chapter 34, Pipe Sizing, and the Systems Handbook Chapters 25 through 27, Liquid Overfeed Systems, Systems Practices for Halocarbon Refrigerants and System Practices for Ammonia. It is recommended that these references be consulted for further system design assistance.

Basically, careful attention must be given to the following three design considerations for refrigerant piping; pressure drop, compressor protection and oil return.

Pressure Drop

All piping (liquid, discharge and suction) should be as small as possible from the standpoint of economy, and as large as possible from the standpoint of minimizing operating penalties that result from pressure drop. The optimum sizing may vary from system to system.

Refrigerant liquid piping from receiver to system presents minimum design problems. If the pressure is reduced either because of line pressure loss or static head loss due to an elevation change, some of the liquid will flash to the vapor state. Excessive flash gas results in reduced capacity and erratic operation of control valves. If control valves are below the receiver, the static head gain will help to reduce flashing. If piping runs and elevations are such that excessive flash gas is generated, liquid subcooling should be employed. This may be done with a subcooling coil in the evaporative condenser (see BAC Evaporative Condenser Engineering Manual, Bulletin E115/1-0), or with a shell and coil suction-liquid heat exchanger in the system suction line, or with a shell and coil direct expansion subcooler, depending on the amount of subcooling that is necessary.

Refrigerant liquid drain lines from condenser to receiver should be designed to allow condenser liquid to freely drain from the condenser. Consult the B.A.C. Evaporative Condenser Engineering Manual, Bulletin E115/1-0, for specific recommendations on piping between the condenser and receiver.

From the standpoint of pressure drop, sizing of compressor discharge lines that carry hot gas to the condensers is straightforward. Again the objective is to achieve the right balance between installed cost and the penalty the pressure drop imposes on the efficiency of the system. Since this portion of the piping is transporting high pressure refrigerant, a relatively high pressure drop per unit length is permissible. Consult the ASHRAE Handbook of Fundamentals, Chapter 34, Pipe Sizing, for complete data on the selection of discharge line pipe size.

The compressor suction line is the most critical aspect of refrigerant piping system design; since it conveys a low pressure vapor, the suction line is most sensitive to pressure drop. When a gravity flooded or liquid recirculation feed system is used, the sole criteria for selecting the suction line size is pressure drop. However when direct expansion feed is used with a halocarbon refrigerant, the suction line is also required to carry oil back to the compressor. Therefore the vapor must have sufficient velocity to keep the oil entrained in it. This becomes particularly important in vertical pipe risers. Vertical risers should be sized on the basis of the minimum velocity required to maintain oil entrainment. If these higher vapor velocities result in too great an overall pressure drop, the criteria for the horizontal runs must be reduced so as to effect a satisfactory system pressure drop. The ASHRAE Systems Handbook, Chapter 26, System Practices for Halocarbon Refrigerants, and ASHRAE Fundementals Handbook, Chapter 34, Pipe Sizing contain complete data for properly sizing suction lines.

Compressor Protection

The second consideration for refrigerant piping design is compressor protection. Reciprocating compressors and to a lesser extent rotary screw machines are sensitive to slugs of liquid refrigerant and/or oil. System piping must reflect this sensitivity by the use of oil separators, traps, and suction-liquid heat exchangers. Much of this compressor protective equipment is related to effective oil return and is covered in more detail under the oil return section of this discussion.

In addition to protective equipment the piping itself must be run to effect safe compressor operation. All suction piping should be pitched toward suction line traps or accumulators. All discharge piping should pitch toward the discharge line oil separator. Individual compressor connections should connect to suction and

discharge headers above the center line. The riser to the evaporative condenser should rise above and connect into the top of the condenser inlet header. Finally, suction and liquid line strainers or catch-alls should be used as necessary to ensure flow of clean refrigerant to the compressors.

Oil Return

Oil is required for lubrication purposes in the case of reciprocating compressors and for lubrication, gas cooling and rotor sealing in the case of rotary screw compressors. Refrigerant comes in contact with this oil in the compressor and even with highly efficient discharge line oil separators, a small portion of the oil is carried around the refrigeration system. This is particularly true in the case of the halocarbon refrigerants which are all miscible with oil, some to a greater degree than others. This oil tends to accumulate in the ice builder which is the point of low pressure and temperature, and the system design must be such that the oil is returned to the compressor in the same amount that it leaves. Oil return systems require different treatment depending on the type of evaporator feed. Since most ice builder systems utilizing R-22 are combinations of direct expansion feed and reciprocating compressors, or liquid recirculation feed and screw compressors, oil return considerations for those two designs will be discussed.

As stated in the preceding section on pressure drop, when thermal valve feed is used, oil return to a single compressor is accomplished by maintaining sufficient vapor velocity through the evaporator (ice builder coil) and the suction line.

When a liquid recirculating system with a refrigerant pump is used to feed the ice builder, the accumulator separates the liquid-vapor mixture returning from the ice builder. Any oil entrained in that mixture stays in the accumulator and cannot return through the suction line. However, a tap off the liquid recirculating pump affords a simple and effective oil return. Pump discharge pressure is usually set at 20 to 25 psi above the suction pressure so there is ample pressure to carry the oil/refrigerant mixture to an expansion valve where it can be flashed to the lower suction line pressure. This pressure drop vaporizes the refrigerant liquid, and the resulting oil/vapor mixture can be piped into the screw compressor suction line. This arrangement is shown in Figure 15.

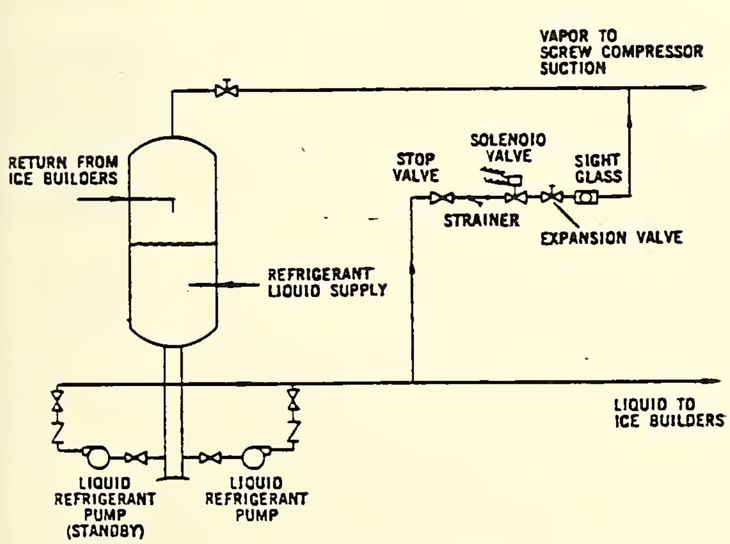


FIGURE 15: Oil Return From Liquid Recirculation Feed System To Screw Compressor Suction Line

Oil recovery from ammonia systems is relatively simple since oil and ammonia are not miscible. Discharge oil separators are employed to recover any oil and that is pumped out into the system by the compressors. The recovered oil is fed back to the crankcase of a reciprocating compressor through a float valve. (A screw compressor has an integral oil separator which feeds the recovered oil directly back to the compressor.) See ASHRAE System Handbook, Chapter 27, System Practices for Ammonia, for complete recommendations.

WATER PIPING

There are five basic water connections on an ice builder unit: chilled water outlet, return water inlet, make-up, overflow, drain. Figure 16 shows the general piping arrangement for these connections. The chilled water and return water connecton both require flow control valves in order to properly balance the system water flow to and from the ice builder. The make-up connection is located above the water level and can be manually or automatically controlled. A valved drain connection is also required, to permit the ice builder to be emptied to a floor drain or other waste area. The ice builder is provided with an overflow connection which should also be piped to a drain area.

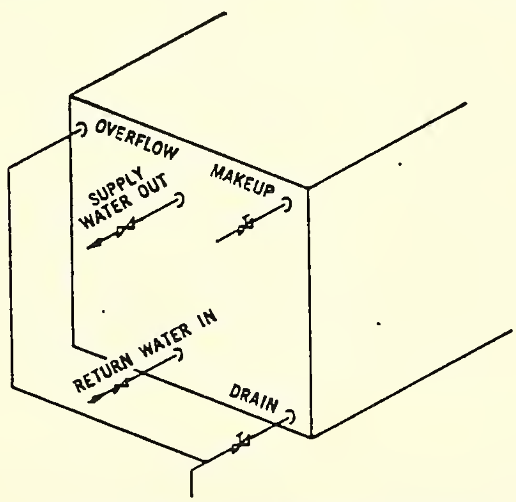


FIGURE 16: Typical Ice Builder Water Piping

Multiple Ice-Builder Installations

There are two possible ways to connect multiple ice builders to the chilled water circuit, parallel and series. Parallel connection, as shown in Figure 17, is the least expensive approach in terms of first cost, since it involves the least number of valves and fittings. However, the parallel method is the most expensive to operate. With this method, all ice builders melt down by the same amount when cooling is required by the system. If the ice charge is only partially melted, then all ice builders must begin recharging with a partial thickness of ice on the coils, which acts as an insulator in the heat transfer process and requires more energy per unit weight of ice during the re-charging process.

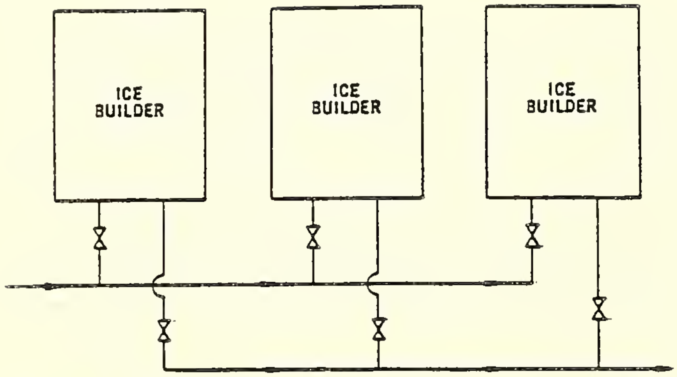


FIGURE 17: Multiple Ice Builder Water Piping, Parallel Arrangement

A series water flow arrangement and melt-down (Figure 18) is more efficient, but is higher in first cost than the parallel method. Each ice builder is provided with isolation valves and a bypass valve to allow the full flow of water to pass through each ice builder individually and melt it down completely before the water is circulated through the next ice builder. This assures minimum power requirements during the rebuild process. However, no less than 25% of the total ice capacity should be isolated for meltdown at any one time. Any greater degree of isolation will produce excessive water flow rates through the ice builder(s).

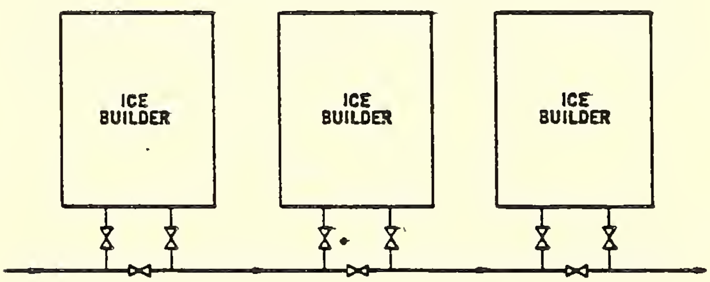


Figure 18: Multiple Ice Builder Water Piping, Series Arrangement

Equalization

When two or more ice builders are connected in parallel, a water equalizing line should be provided between adjacent ice builders, as shown in Figure 19. This prevents inadvertant emptying or filling of an ice builder that could result if the flow control valves are not properly adjusted. It also prevents unnecessary overflow that could occur if the water flow rates from each ice builder became unbalanced due to an obstruction in the line, such as a clogged outlet.

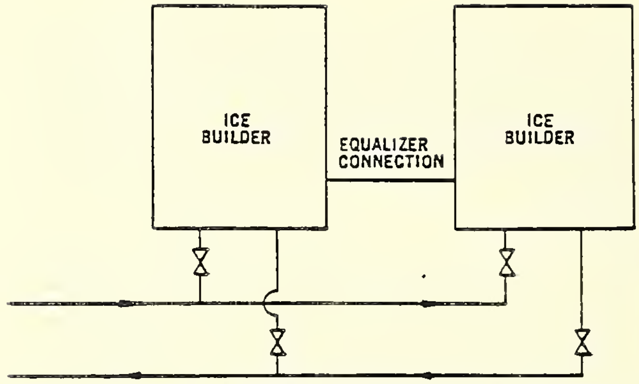


FIGURE 19: Multiple Ice Builder Water Piping, Parallel Operation, With Equalizing Connection

The size of the equalizer connection is a function of the design water flow rate through one ice builder, and should be selected from the following table:

ICE BUILDER FLOW RATE, GPM	EQUALIZER PIPE SIZE, IN.
Up to 120	3
121-240	4
241-630	6
631-1170	8
1171-1925	10
1926-2820	12

If the ice builders are not the same size, select the equalizer connection size on the basis of the flow rate through the largest ice builder.

ACCESS

The space required by an ice builder must include an area around its perimeter to provide access for servicing purposes, and in the case of multiple ice builders, to provided a space for installing water equalizing connections. An access lane of at least 3 feet is recommended along with each side, and between adjacent ice builders. A minimum space of 6 feet in width should be provided on any size where water connections are made. See Figure 20 for a typical layout.

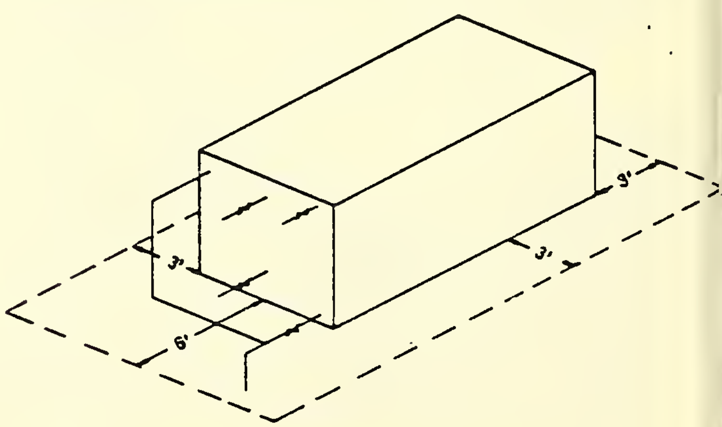


FIGURE 20: Minimum Access Requirements

CONTROL

The various components of the refrigeration system require a specific control sequence to ensure proper ice building and meltdown. The control sequence and activating parameters for the full and partial systems are shown in Table 2 and are fully described below.

TABLE 2

	Ice Charging	Meltdown	Control Point
Full Ice Storage System:			
Compressor	On	Off	Ice Thickness Sensor/Timer
Condenser Fan Motor	On	Off	Condensing Pressure
Condenser Pump Motor	On	Off	Condensing Pressure
Refrigerant Pump*	On	Off	Interlocked w/Compressor
Air Pump	On	On	Ice Thickness Sensor
Chilled Water Pump	Off	On	Timer
Refrigerant Control Valves	Open	Closed	Interlocked w/Compressor
Partial Ice Storage System:			
Compressor	On	On	Ice Thickness Sensor
Condenser Fan Motor	On	On	Condensing Pressure
Condenser Pump Motor	On	On	Condensing Pressure
Refrigerant Pump*	On	On	Interlocked w/Compressor
Air Pump	On	On	Ice Thickness Sensor
Chilled Water Pump	Off	On	Timer
Refrigerant Control Valve	Open	Open	Interlocked w/Compressor

**Optional: Liquid Recirculation Systems Only.*

Full Storage System

In the full storage system, the refrigeration system is operated to build ice only during periods of no cooling load, when utility rates are usually lower. A timer should be used to restrict operation of the compressor to periods of no load. The compressor is activated (and deactivated) by a maximum ice thickness sensor that is furnished with the ice builder. When the ice thickness is less than maximum, the compressor is permitted to operate and rebuild the ice charge. When maximum ice thickness is obtained, a signal from the ice thickness sensor shuts off the compressor.

The condenser operates in response to condensing pressure. Pressure controllers are used to activate the condenser fan and pump motors when a maximum condensing pressure is reached, and to shut down the condenser at a minimum condensing pressure.

The refrigerant pump (liquid recirculation system only) and the refrigerant control valves are interlocked with the compressor controls so that when the compressor is operating, the refrigerant pump is on, and the flow control valves are open. When the compressor is off as it is during the ice meltdown, the refrigerant pump is off and the refrigerant flow control valves are closed.

The air pump for agitating the water in the ice builder must be operational during *both* the ice charging *and* meltdown modes. Air agitation is necessary for uniform ice formation, and for consistent minimum water temperatures during meltdown. Therefore the air pump should be controlled by the ice thickness sensor so that the pump is on at *any time* when the ice thickness is less than maximum.

Operation of the system chilled water pump should be controlled by a timer.

Partial Storage System

With a partial storage system, the ice furnishes a part of the cooling load and the refrigeration system is used to supplement the ice capacity during meltdown. Therefore operation of the compressor and other components is required during the meltdown process, so the compressor is controlled solely by the ice thickness sensor. Whenever the ice thickness is less than maximum, the compressor must operate.

As in the full storage system, the condenser fan and pump motors operate in response to condensing pressure, and pressure controllers are used for this purpose.

The refrigerant pump (liquid recirculation system only) and the refrigerant control valves are interlocked with the compressor controls, so that when the compressor is operating, the refrigerant pump is on and the flow control valves are open. When the compressor is off, the refrigerant pump is off and the refrigerant flow control valves are closed.

The air pump for agitating the water in the ice builder must be operational during *both* the ice charging *and* meltdown modes. Therefore the air pump should be controlled directly by the ice thickness sensor, or interlocked with the compressor.

Operation of the system chilled water pump should be controlled by a timer.

Special Applications

SECONDARY WATER LOOP HEAT EXCHANGER

Some very important benefits can be realized by adding a heat exchanger to the secondary water circuit of an ice builder system, i.e., the circuit that carries the chilled water from the ice builder to the cooling coils.

This arrangement is shown in Figure 21. Addition of the heat exchanger to the system can have any or all of these advantages:

1. Reduce the total water pumping energy requirements. This is especially true in the case of a multi-floor building, which would require a relatively high head capability on the secondary water pump in order to overcome the static head above the ice builder as well as the friction loss. The loop between the ice builder and the heat exchanger is open, so it should be as short as possible to minimize pump head. Since the chilled water loop is closed, the chilled water pump has to overcome only friction loss in that circuit. As a result, the total pumping energy requirements of the system are significantly reduced, despite the need for a third water pump.
2. Closed loop to cooling coils keeps water clean. Although ice builders are furnished with covers, they are not air-tight, and foreign matter can penetrate the enclosure to contaminate the water. The use of a heat exchanger minimizes the open portion of the circuit and provides a clean, closed water circuit for the cooling coils.
3. Eliminates drainage of secondary loop back to the ice builder. If the secondary water loop is open, the water may drain back to the ice builder on shut-down, and possibly cause overflow and waste of water. Closing the secondary loop prevents this, or eliminates the need for manual or automatic shutoff valves.

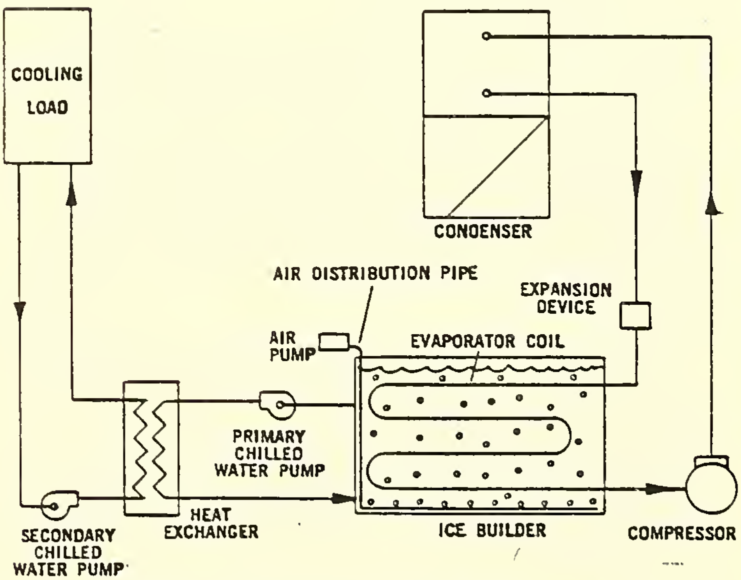


FIGURE 21: Ice Storage System With Heat Exchanger

LOWER CHILLED WATER TEMPERATURE BENEFITS

Chilled water storage systems are commonly designed for 40° to 42°F chilled water supply temperature, and cooling coils are selected accordingly. However, the compressor-aided system provides 35°F chilled water, which in many cases can result in attractive cost-saving benefits. (This does not apply to systems using a heat exchanger in the secondary water loop.)

The lower water temperature can be utilized in either of two ways: increased water temperature range, or decreased return water (conventional range). Increasing the water temperature range has these benefits:

1. Smaller and lower cost pump, since water flow is reduced by virtue of the increased temperature differential.
2. Smaller pipe sizes, also as a result of proportionately reduced flow.

Use of a conventional temperature differential (usually 10°F) and decreasing the return water temperature results in these benefits:

1. Increases the temperature differential in the cooling coils, thereby reducing the required amount of heat transfer surface, and the cost of the coils.
2. Air flow volume is reduced, which reduces the power required to move the air, and the size and cost of the ductwork.

It should be noted that with either approach, the lower chilled water temperature will increase the de-humidification effect in the cooling coils, which may not always be desirable.

Thermal storage systems have long been used to save first cost on applications where cooling loads are infrequent and of short duration. However, as demand for electric power continues to grow and utility companies approach full capacity, the utilities attempt to avoid or delay the high cost of construction of additional capacity. As a result, power rate structures are being implemented that include penalties for operation during peak hours. These penalties, in the form of demand charges and/or high energy charges during peak use times, are likely to increase in magnitude and become more common in the future. The result is increased pressure for industrial and commercial users of all kinds to shift cooling loads to off-peak hours when electricity costs are low.

Thermal storage systems using ice as a storage medium are an effective means of shifting cooling loads. They are conceptually simple, easy to design, simple to operate, and can have first costs comparable to conventional systems that produce cooling as it is needed. This guide has described several different ice storage systems and provided guidelines for system design so that designers, installers, and users will have a better understanding of how to implement ice storage for their applications.

UNEXPECTED ADVANTAGES FROM ICE COOLING SYSTEMS

C. MacCracken, Calmac Manufacturing Corporation, NJ

The Calmac cooling technique is to couple a standard prepackaged chiller unit to a plastic tube heat exchanger fitted inside a plastic tank. The tanks have diameters and heights of 4 and 6 feet. Capacities are 33 ton hours and 130 ton hours. The pipe is 0.5 in. polyethene, with a length of approximately one mile in the 4 foot unit. Mr. MacCracken states that they do not have expansion problems with these storage systems. The trick is to give the water an escape route. The expansion is vertically upward only.

Mr. MacCracken than listed some unexpected and encouraging observations from an installation in Braintree, Massachusetts.

- The first cost of an ice system is <u>30% lower</u> than that of a conventional system.

- Because the air coming off an ice coil is 38°F to 40°F you have in essence <u>more BTU's per lb. of air</u>.

- Savings are realized due to <u>smaller blowers</u> (CFM is lower) and <u>smaller sized duct systems</u>. The duct system amounts to approximately 1/2 of the total system cost. Small-round Owens Corning Fiberglass duct systems are now being used in place of more expensive sheet metal duckwork.

- There is <u>no frosting of the coils</u> problem in an ice system.

- There are two design options as to storage size:

  (1) Small storage coupled to a 1/2 size chiller that runs 24 hours a day. <u>This option saves 1/2 of the chiller cost plus 1/2 of the demand charges</u>.

  (2) Large storage coupled with the transferring of the day load to night time. With the AC load in the night time hours only, one could have <u>no demand charges</u>.

- <u>Air-conditioning with ice saves energy</u>. A conventional system operates normally at 60% RH and 75°F thermostatic setting. With 30% RH off an ice system, only on 80°F thermostatic setting is required for human comfort. A savings of 5°F can be obtained by the use of a ice AC system.

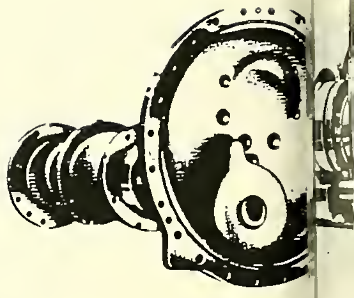
- It is possible that <u>much less ventilation air</u> is required in a building cooled with an ice system. Indications are that with a cold coil, having close fin spacing, an air wash effect is being observed. Smoke and other particle matter is being removed by the high condensation wash of the ice system. If this is indeed the case, another considerable savings of operating cost would be realized.

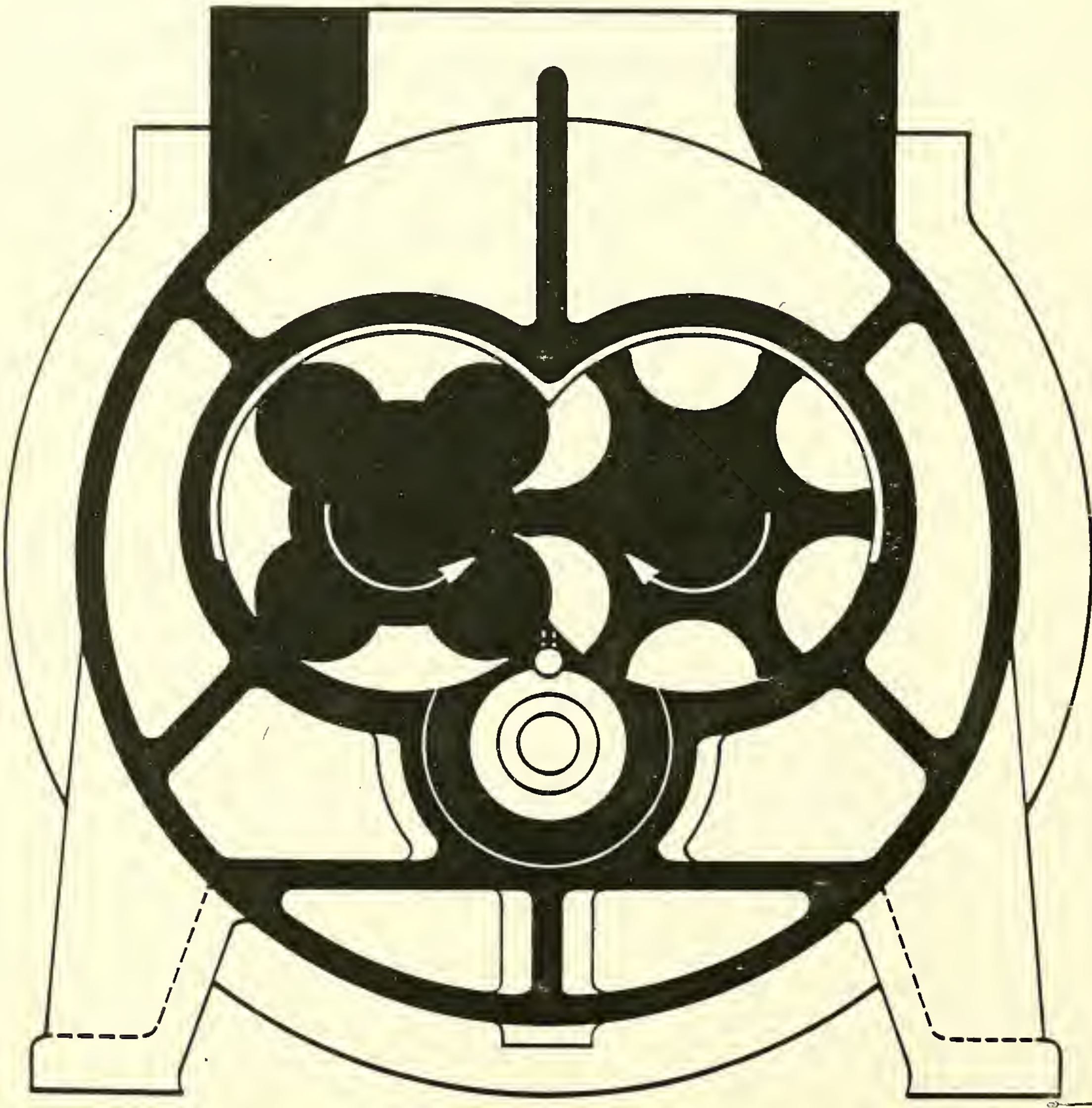
- Operation of the Braintree installation indicates that ice AC systems have a very <u>fast response time</u>. In a conventionally cooled commercial building the AC is normally turned on an hour or so before people arrive. In the Braintree installation, 43°F air was obtained in 17 seconds!

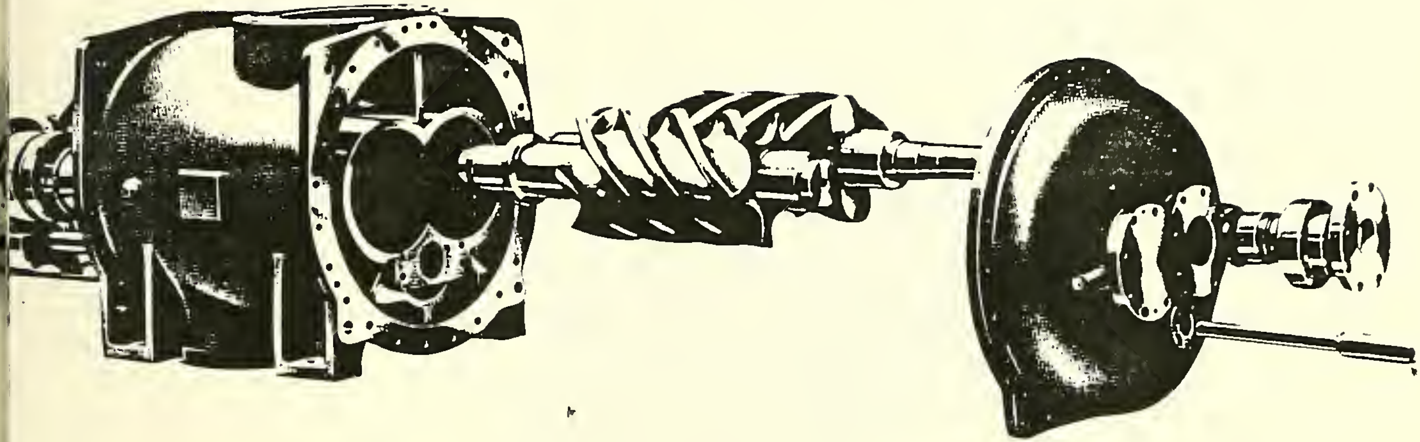
Note that all the benefits mentioned above are only for a partial time air conditioned building. Mr. MacCracken states that these advantages would not all be obtained from a building cooled 24 hours a day. He also stated that in a present-day modern office building the main load is the cooling . Modern office buildings do not need much, if any, space heating.

Advantages of the screw compressor are:

1. The absence of reciprocating motion and the elimination of delivery and suction valves means that there are far fewer moving parts to wear and fatigue. Overhaul periods can be up to 25 000 h, compared to 10 000 h with a comparable reciprocating compressor.
2. The same compressor can operate with evaporation temperatures from +10°C to −40°C in one stage, whereas to obtain low temperatures with reciprocating compressors, two-stage or compound compression is necessary.
3. Output is continuously variable instead of in steps.
4. If due to some fault in the regulation system liquid Freon is drawn in with the suction gas, this will pass through without causing any damage.







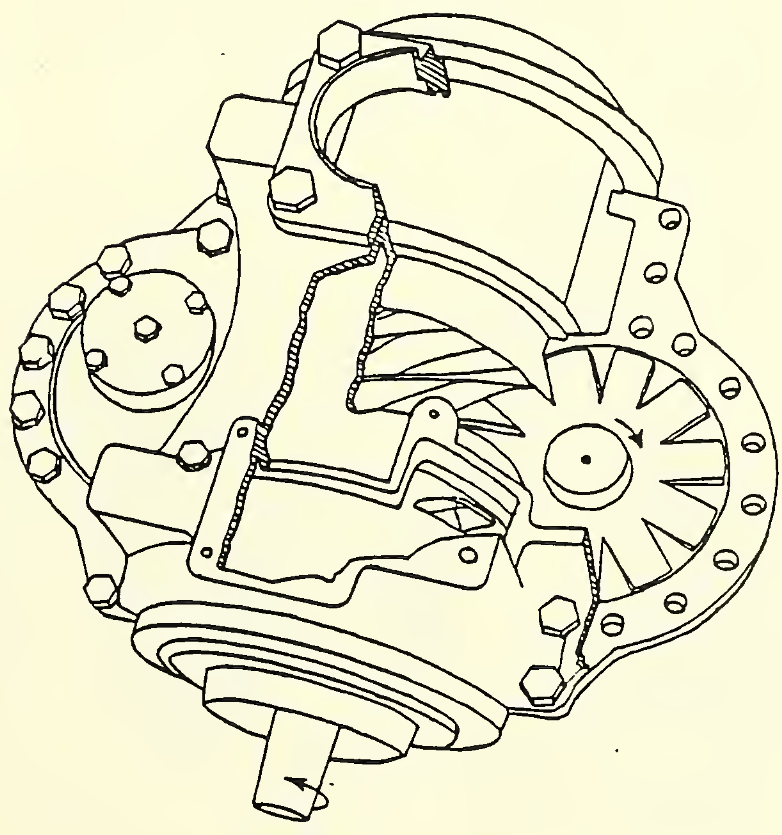


FIG. 30. Single screw compressor.

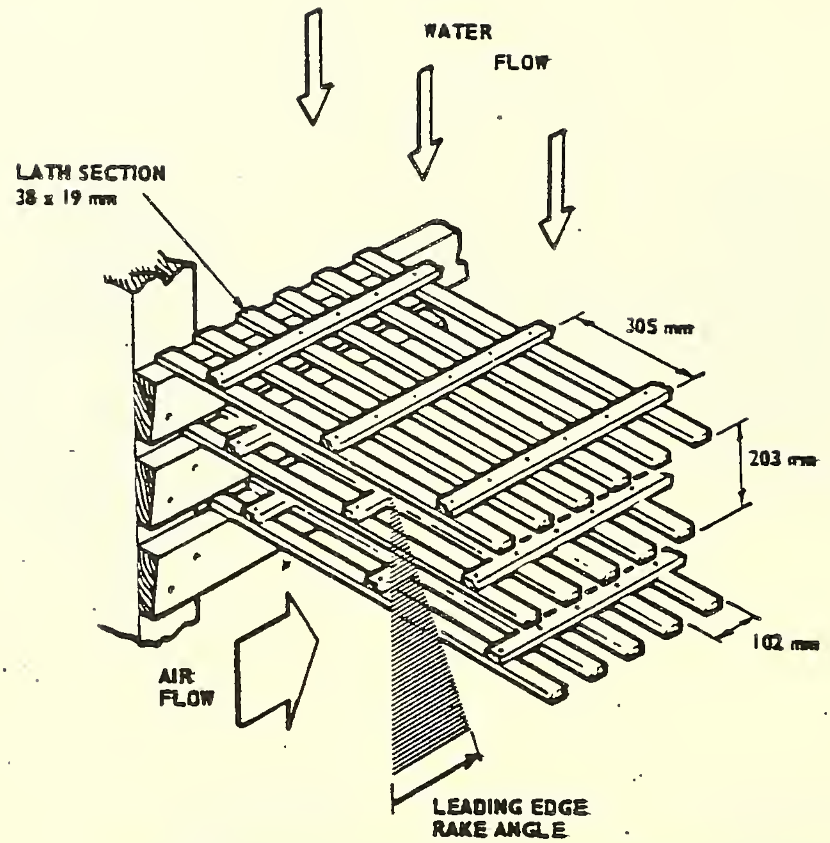


Fig. 5 Layout of packing trays and method of support.

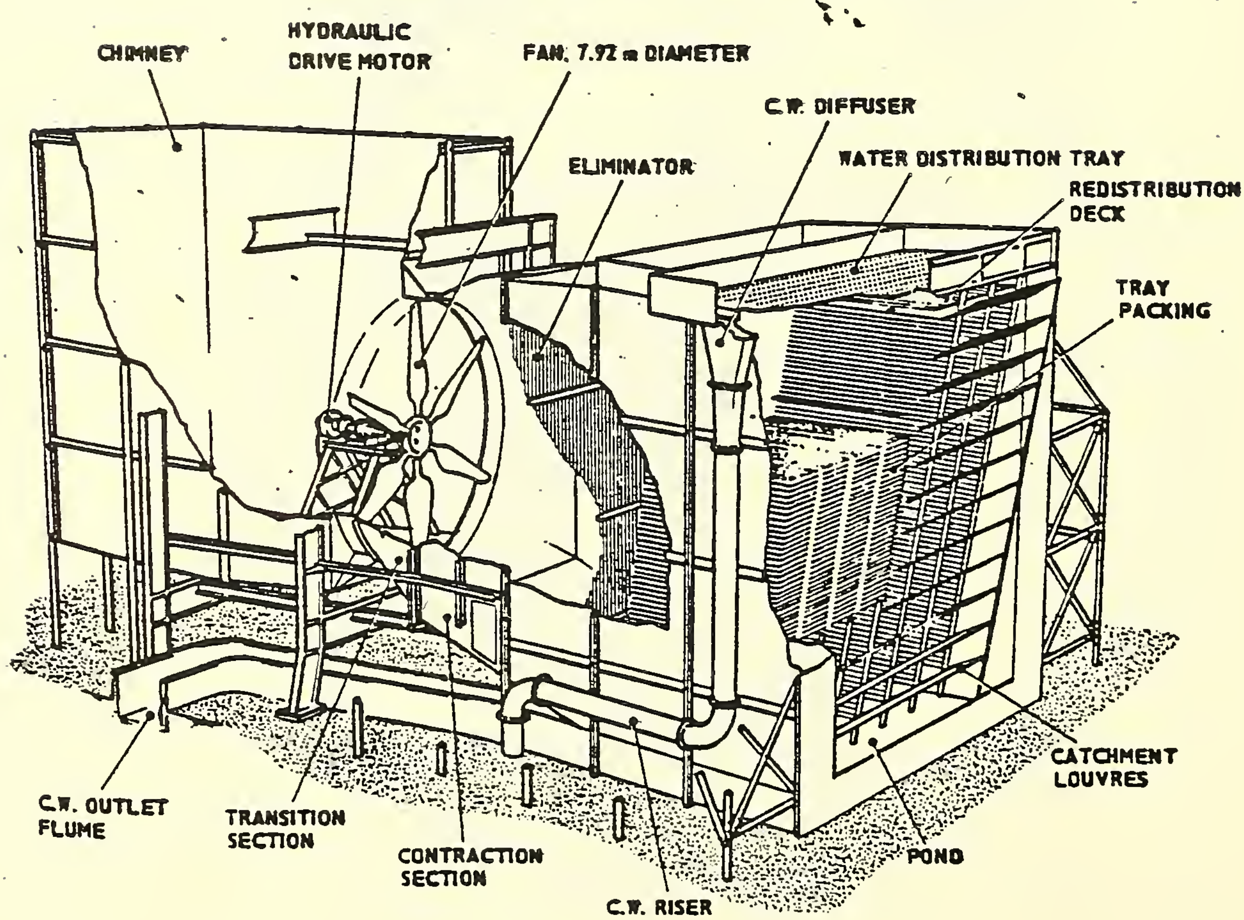


Fig. 6 Full scale cooling tower test cell

BOSTON PROJECTS

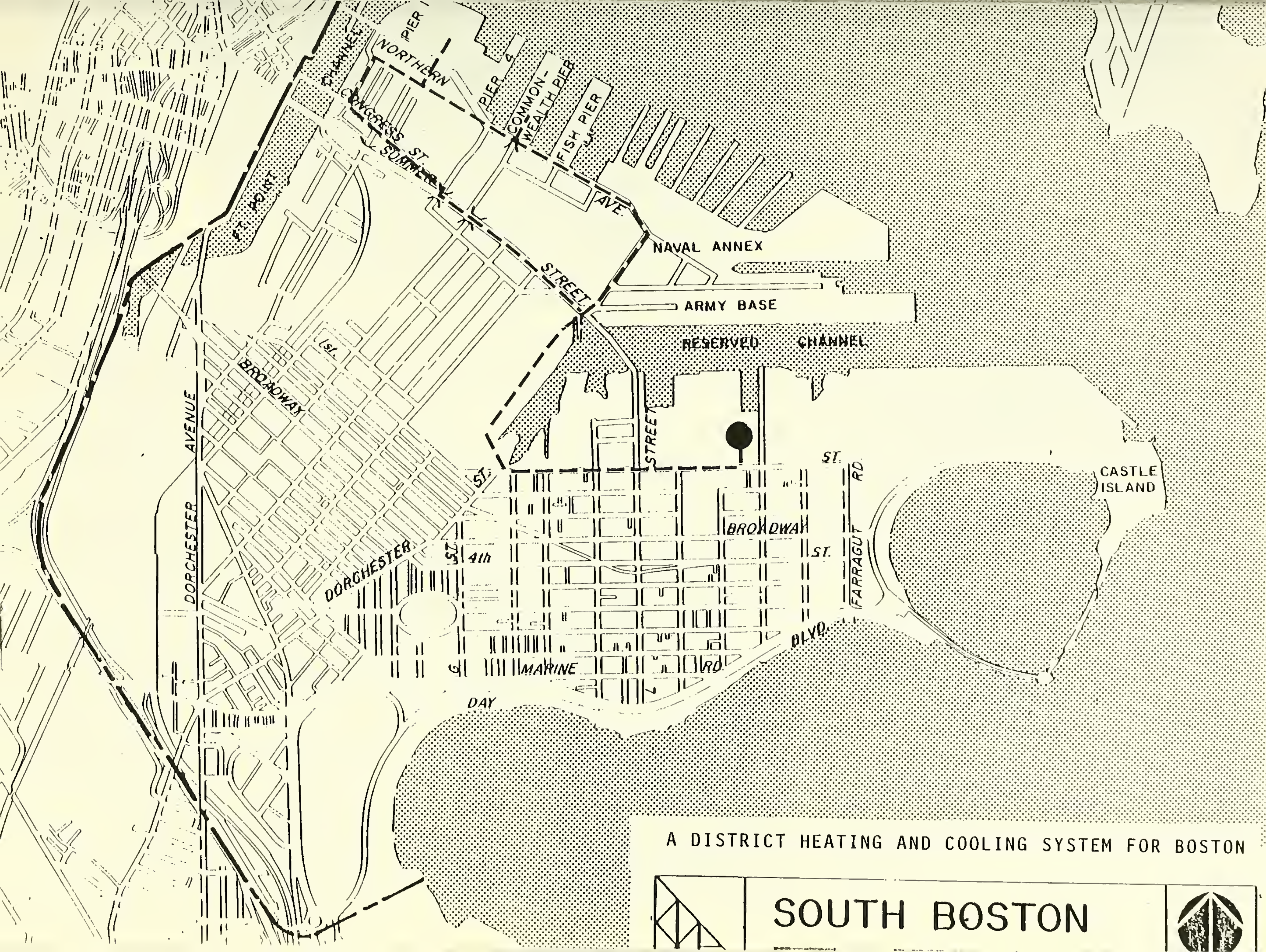
A.10 Large-Scale Projects

The BRA is involved in overseeing and coordinating several large-scale, mixed-use projects which are in advanced stages of planning or have recently begun. These projects are of a magnitude that will generate considerable economic growth, particularly new job opportunities and increased tax revenues. The following is a list of those projects:

- Charlestown Shipyard -- Immobiliare New England, developer (Italian-based). First phase -- 367 housing units, market rate. Parking for 362 cars plus 20 townhouses and marina for 93 boats. Total Phase I private investment $22 million; BRA bought site from GSA for $1.7 million with loan from developer; $2.3 million park underway on 16 acres. Eventual 1,200 housing units on 58 acres, 20,000 square feet industrial space. Project in total will yield $3 million in annual tax revenue. 121A granted with agreement between BRA, Charlestown and developer to give qualified Charlestown residents a first opportunity at jobs generated. Total project $200 million.
- Lafayette Place -- $65 million private investment (including Jordan Marsh portion, project totals $190 million), financing and 121A status secured; city to build $25.8 million, 1,200-car, underground garage, development on air-rights above garage. Mondev-Sefrius joint development, Canada/France respectively, UDAG grant for $8 million received, hotel operator to be Intercontinental Hotels (subsidiary of Pan American World Airways), hotel with 500 rooms and 200,000 square feet retail space, construction started fall, 1979.

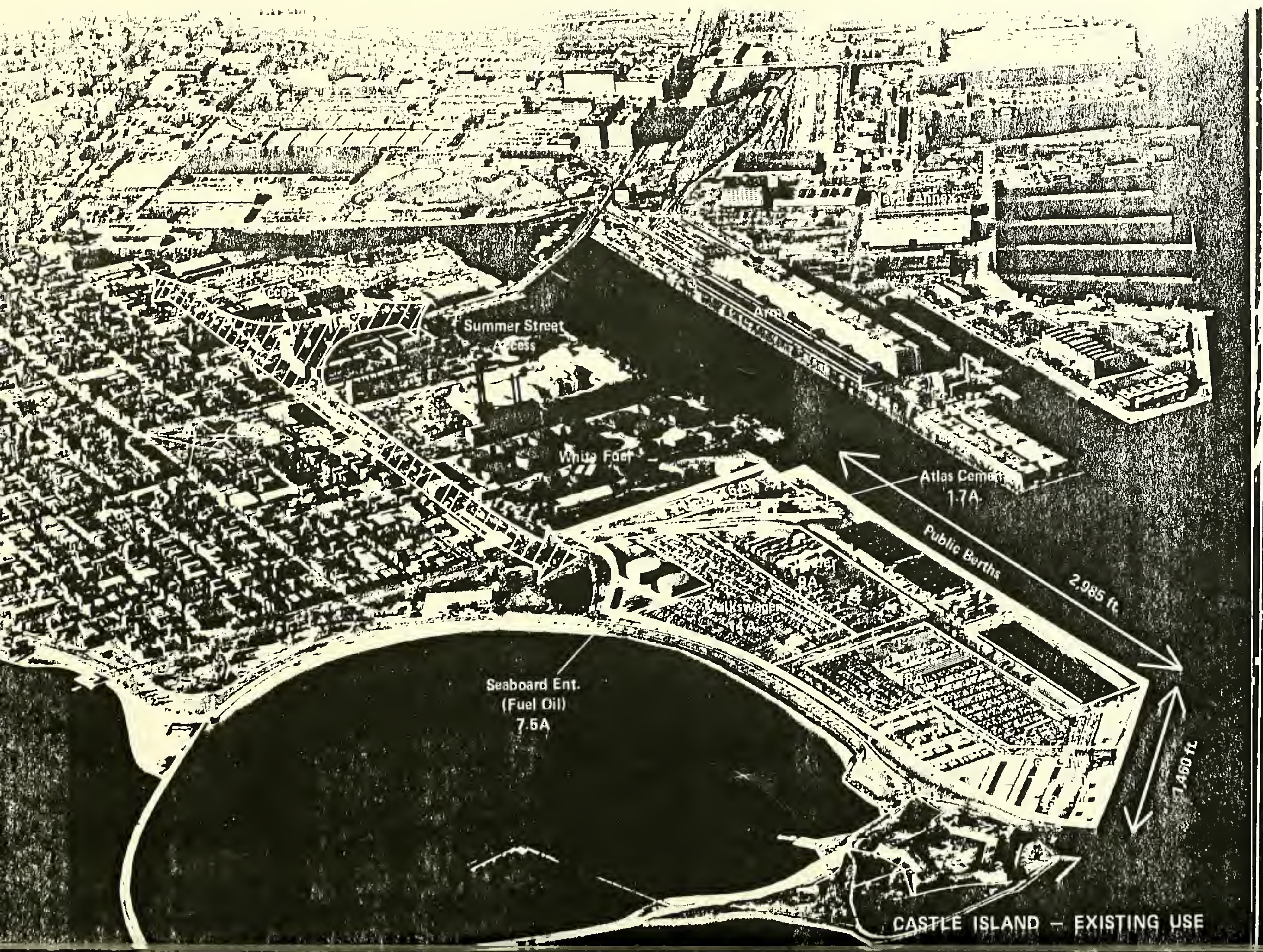
- Copley Place - $300 million cost, Urban Investment and Development Corporation, 121A granted, $211 million permanent financing, $18 to $24 million public funds, $61 million equity; components include 712-room hotel operated by Western International Hotels; 333-car garage; additional 960-room, convention-oriented hotel; 390-foot height limitation on both hotels, 512,000 square feet retail space including a 113,000 square feet specialty store, 200,000 square feet in mall shops, 15,000 square feet in cinemas, a 35,000 square feet health club, 8,000 square feet of community retail, additional 1.200 parking spaces, two office towers totalling 730,000 square feet, 100 units of mixed-income housing; project to be constructed primarily on air-rights over the Mass. Turnpike at Copley Square.

- Old Federal Reserve Site -- Beacon Companies, Developer $65 million project including 300-room luxury hotel on nine floors of recycled Old Federal Reserve Building, a 750,000 square feet, 39-story office building and a 350-car garage. Construction under way with completion in 1981, Planned Development Area status granted, 1.8-acre site, approximately $2 million in property taxes annually.



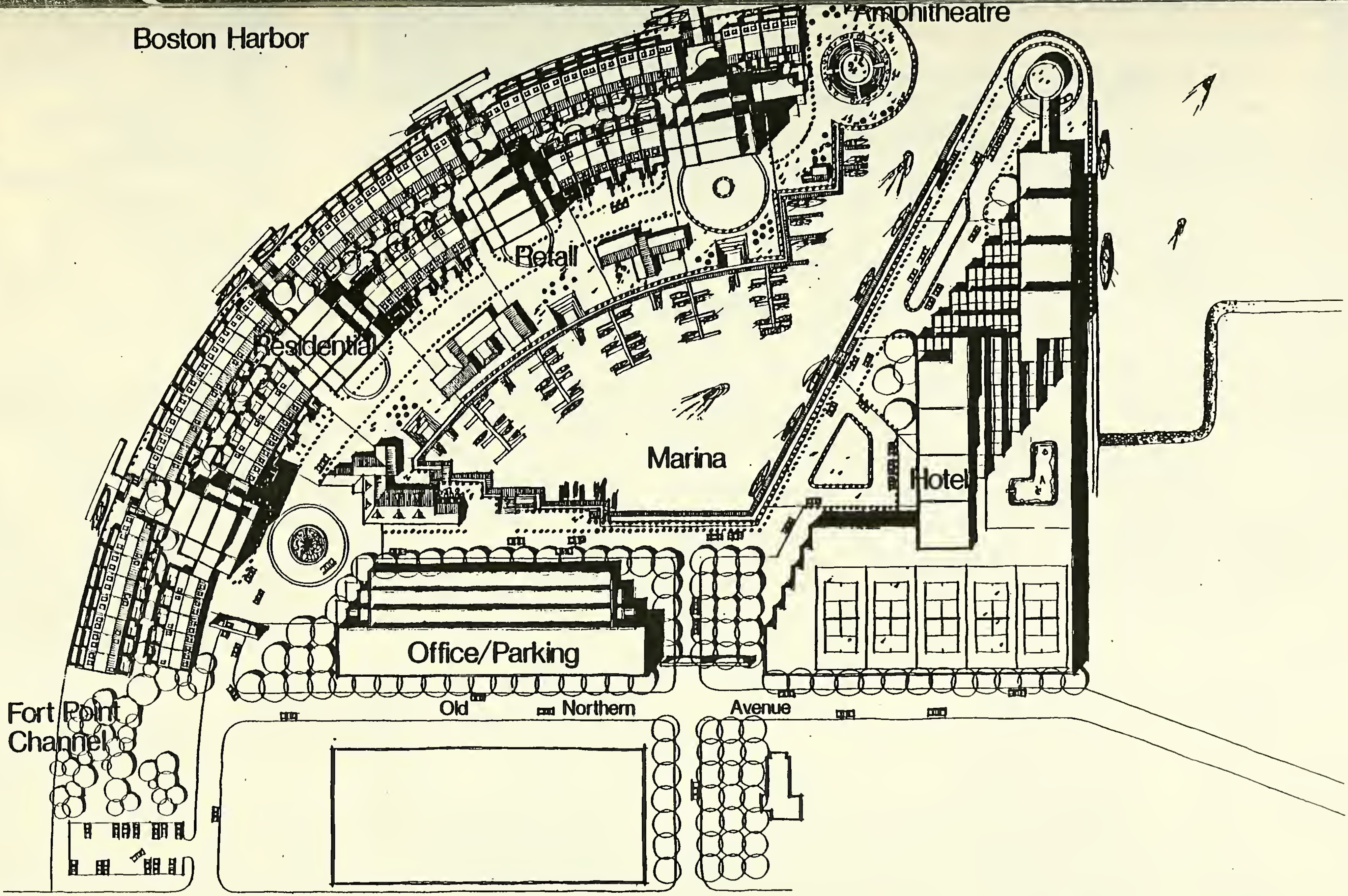
A DISTRICT HEATING AND COOLING SYSTEM FOR BOSTON

SOUTH BOSTON



CASTLE ISLAND — EXISTING USE

Amphitheatre

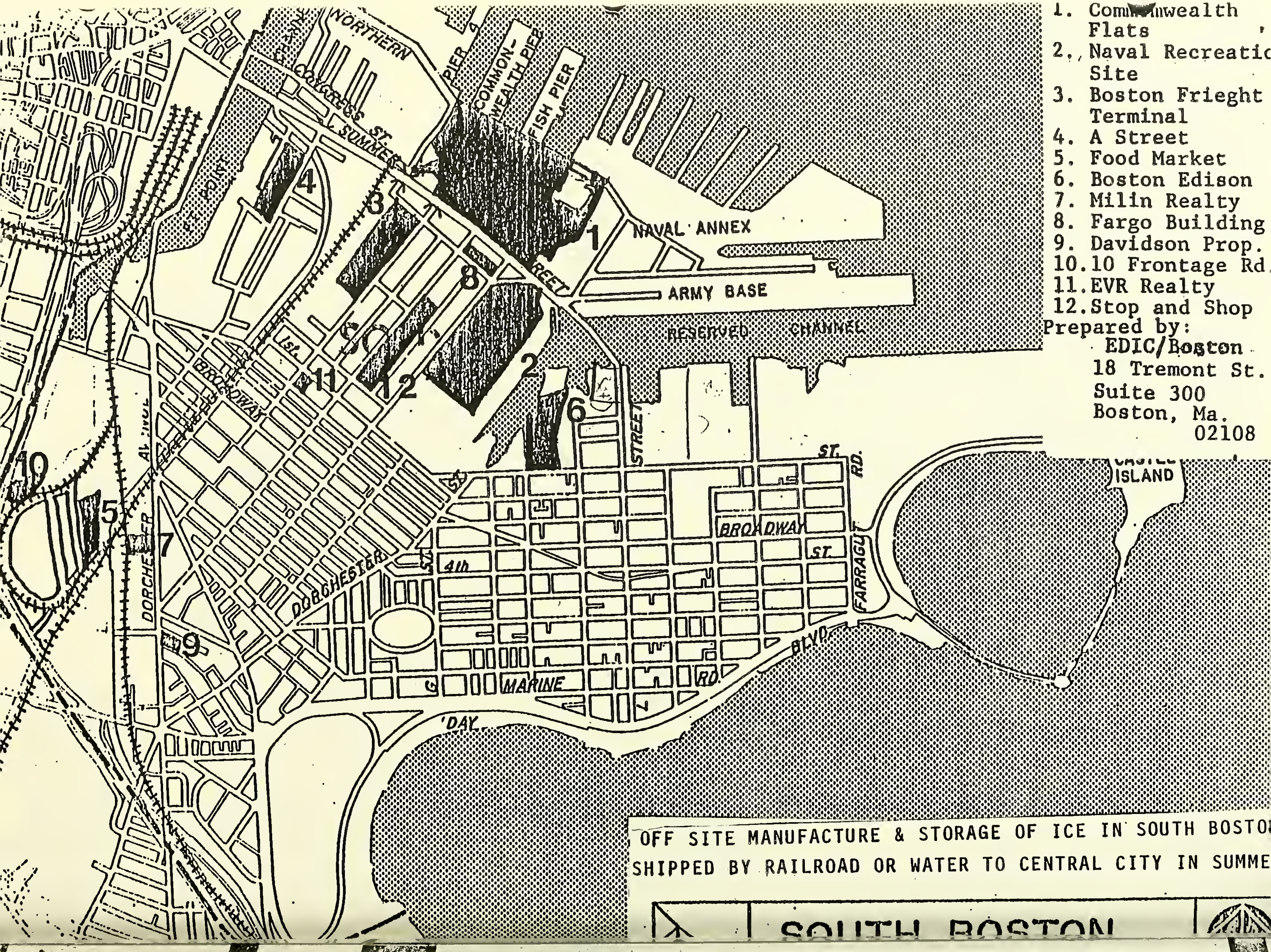


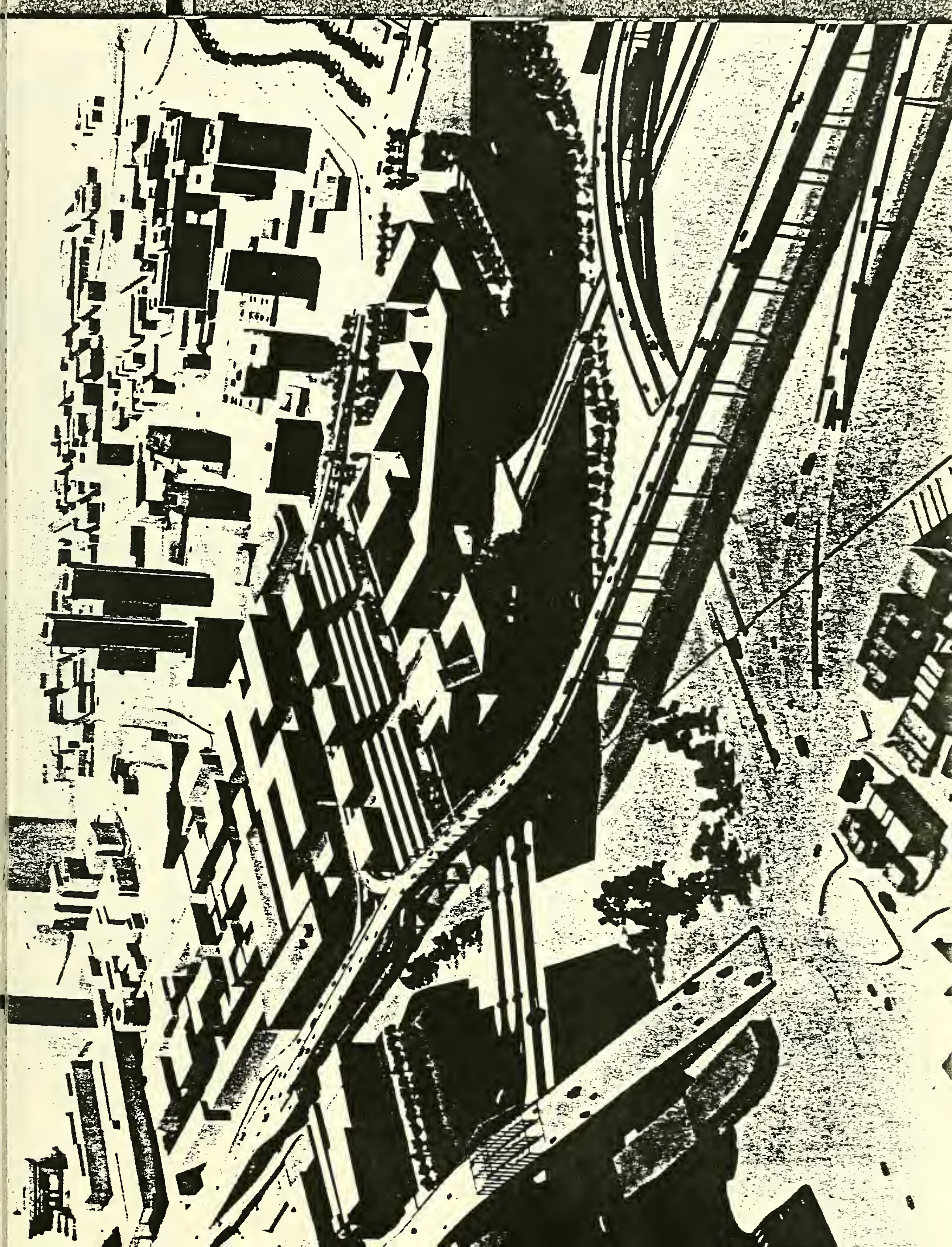
Piers 1.2.3. Boston

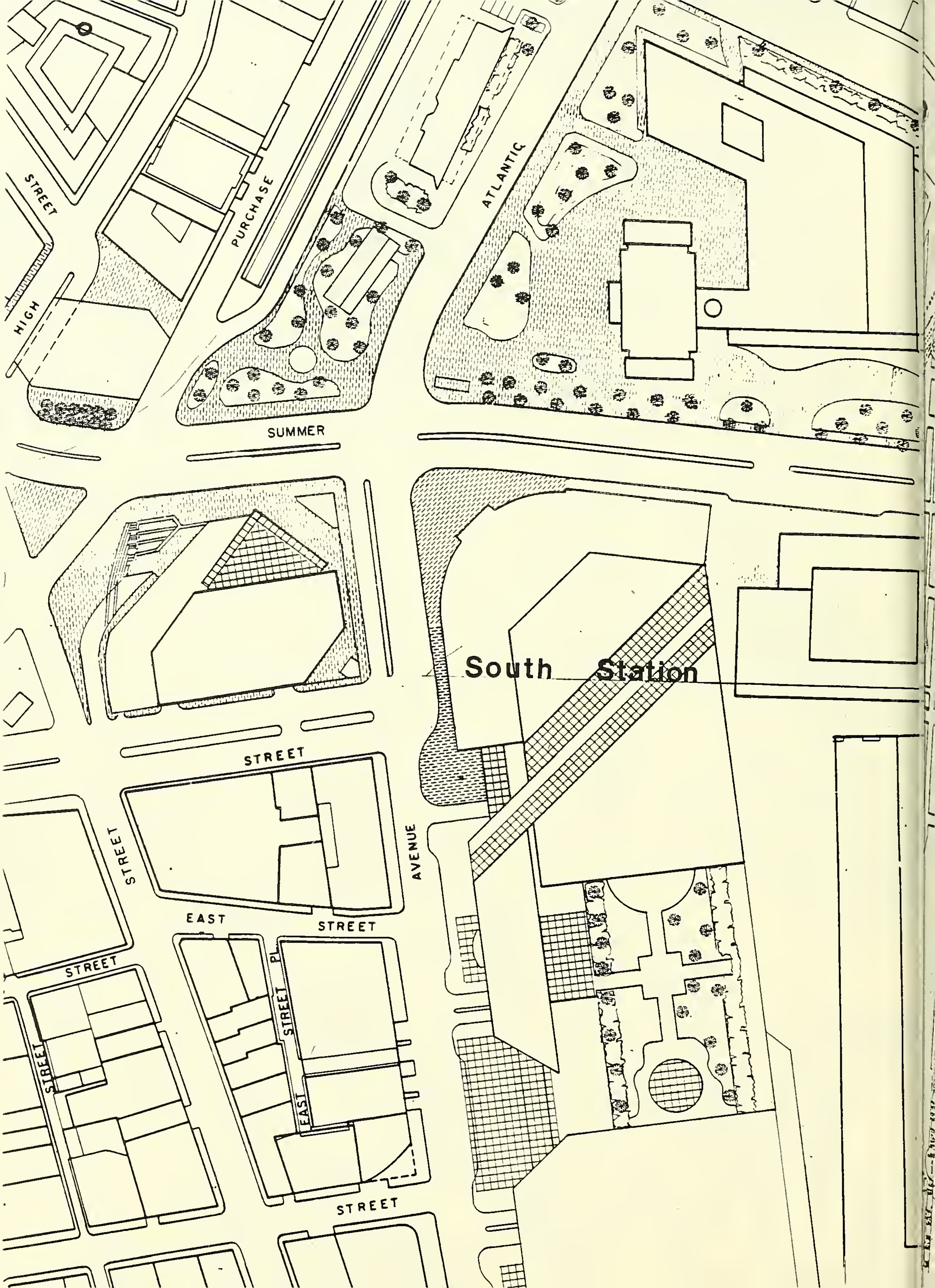
Development Study Plan

Hellmuth, Obata & Kassabaum P.C. · Architects & Planners
The SWA Group · Associate Planners

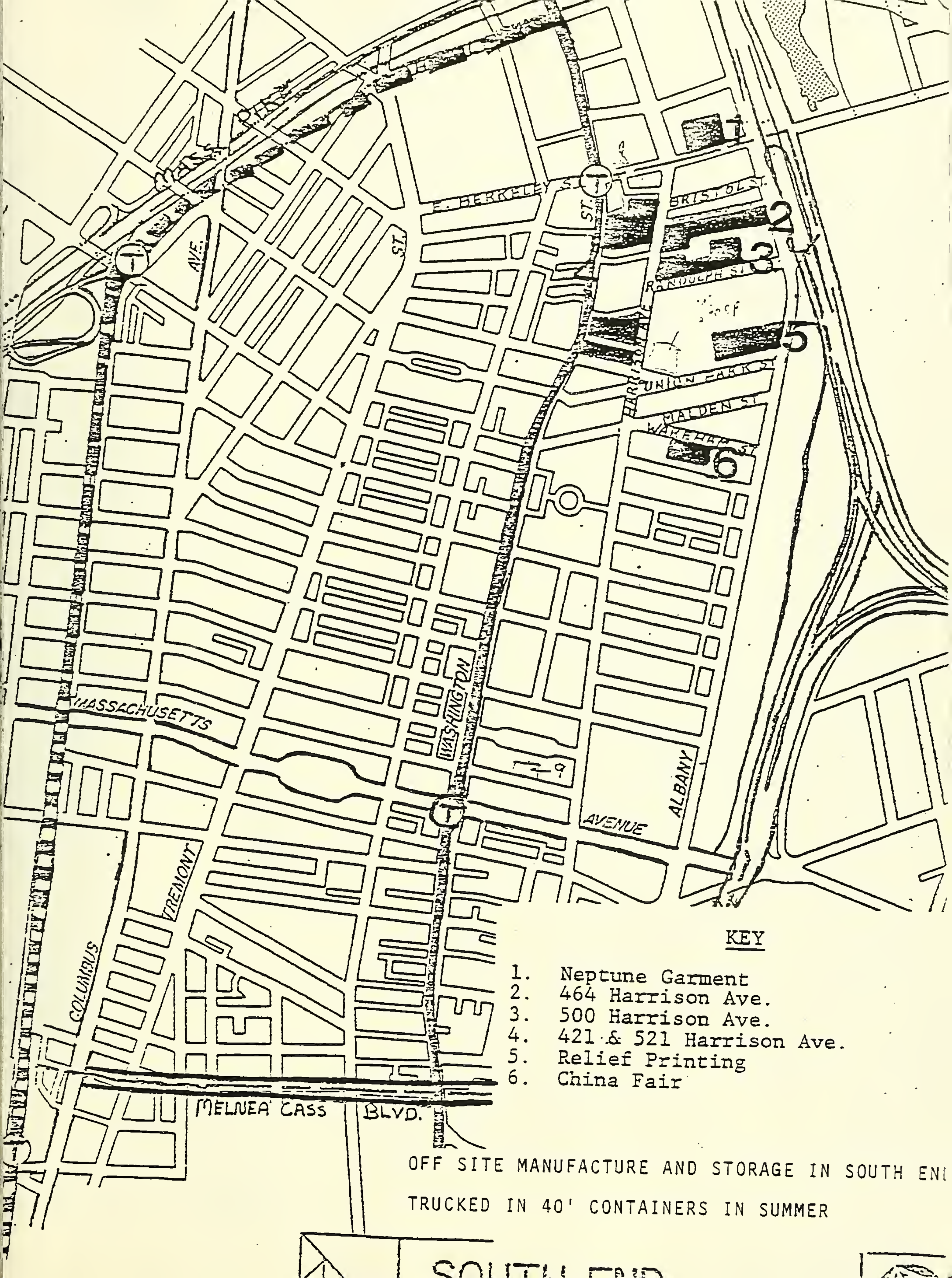
0 32 64 128


NORTHERN
CONGRESS ST.
SUMMER
COMMON-WEALTH PIER
FISH PIER
PIER
NAVAL ANNEX
ARMY BASE
RESERVED CHANNEL
STREET
BROADWAY
DORCHESTER
4th
ST.
MARINE
RD.
DAY
BLVD.
FARRAGUT
CASTLE ISLAND
BROADWAY
1st.
DORCHESTER
1. Commonwealth Flats
2. Naval Recreatic Site
3. Boston Frieght Terminal
4. A Street
5. Food Market
6. Boston Edison
7. Milin Realty
8. Fargo Building
9. Davidson Prop.
10.10 Frontage Rd.
11.EVR Realty
12.Stop and Shop
Prepared by:
EDIC/Boston
18 Tremont St.
Suite 300
Boston, Ma. 02108
OFF SITE MANUFACTURE & STORAGE OF ICE IN SOUTH BOSTO
SHIPPED BY RAILROAD OR WATER TO CENTRAL CITY IN SUMME
SOUTH BOSTON



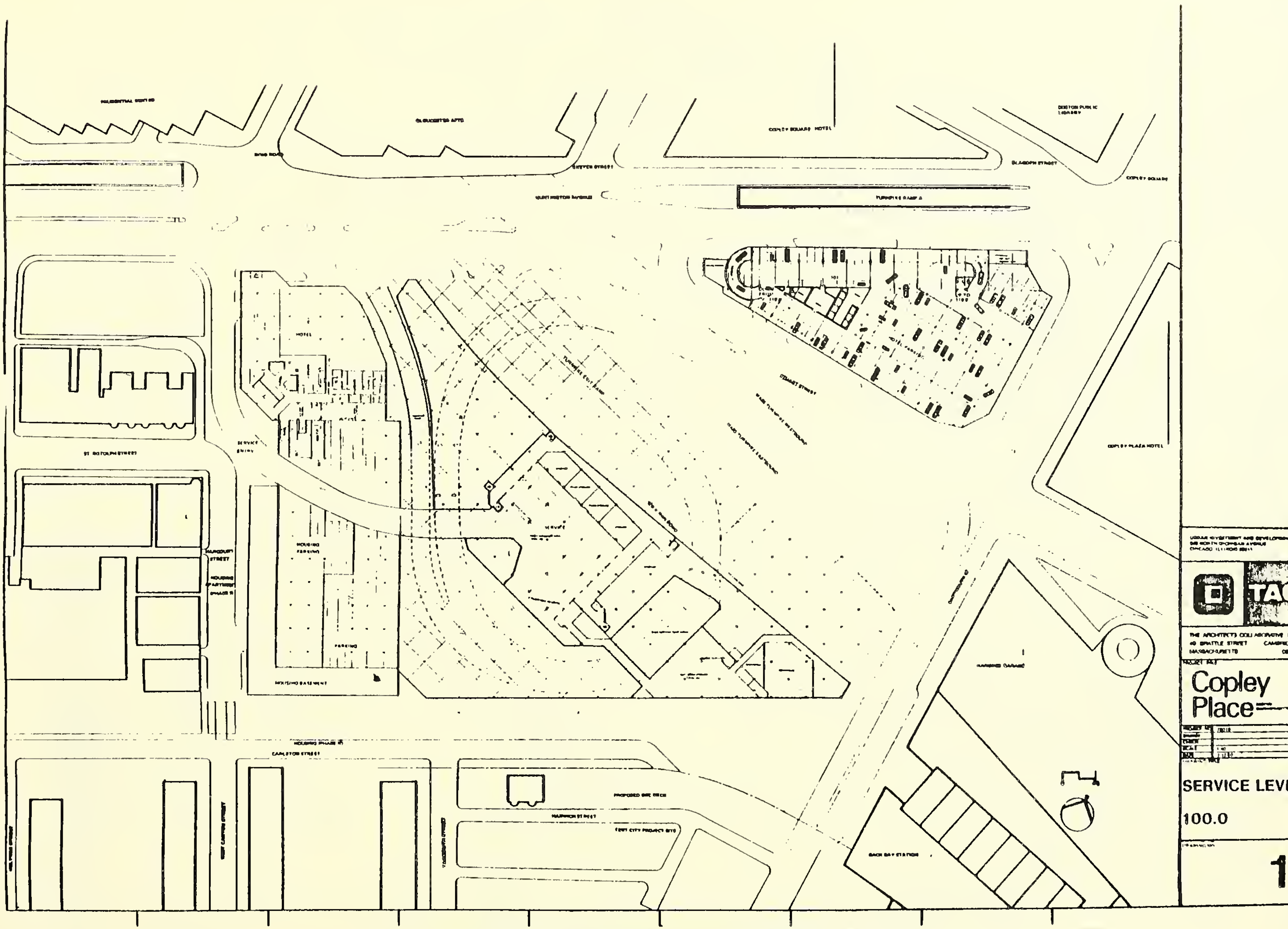


STREET
HIGH
PURCHASE
ATLANTIC
SUMMER
South Station
STREET
STREET
AVENUE
EAST
STREET
STREET
PL
STREET
STREET
EAST
STREET

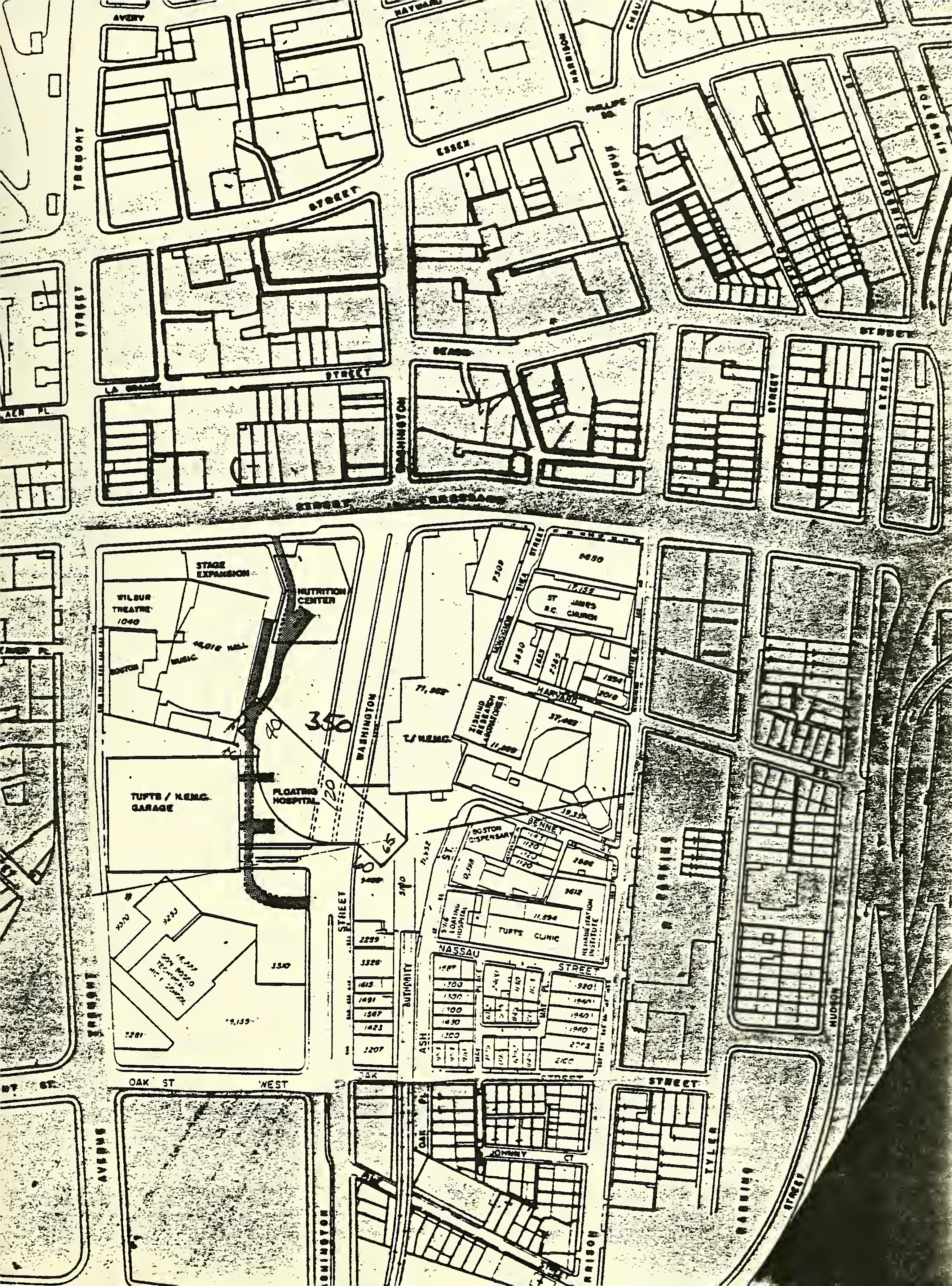


OFF SITE MANUFACTURE AND STORAGE IN SOUTH END

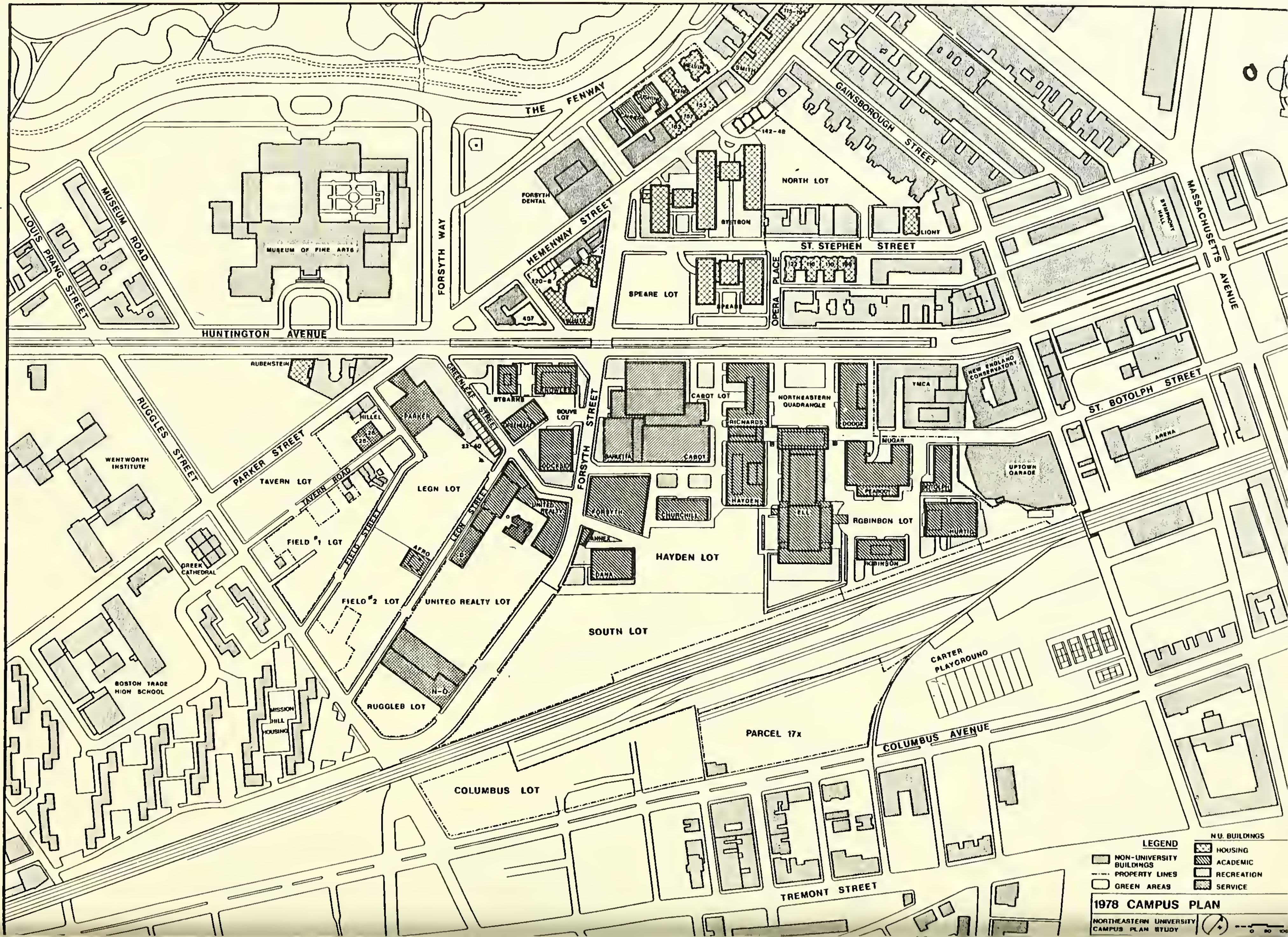
TRUCKED IN 40' CONTAINERS IN SUMMER



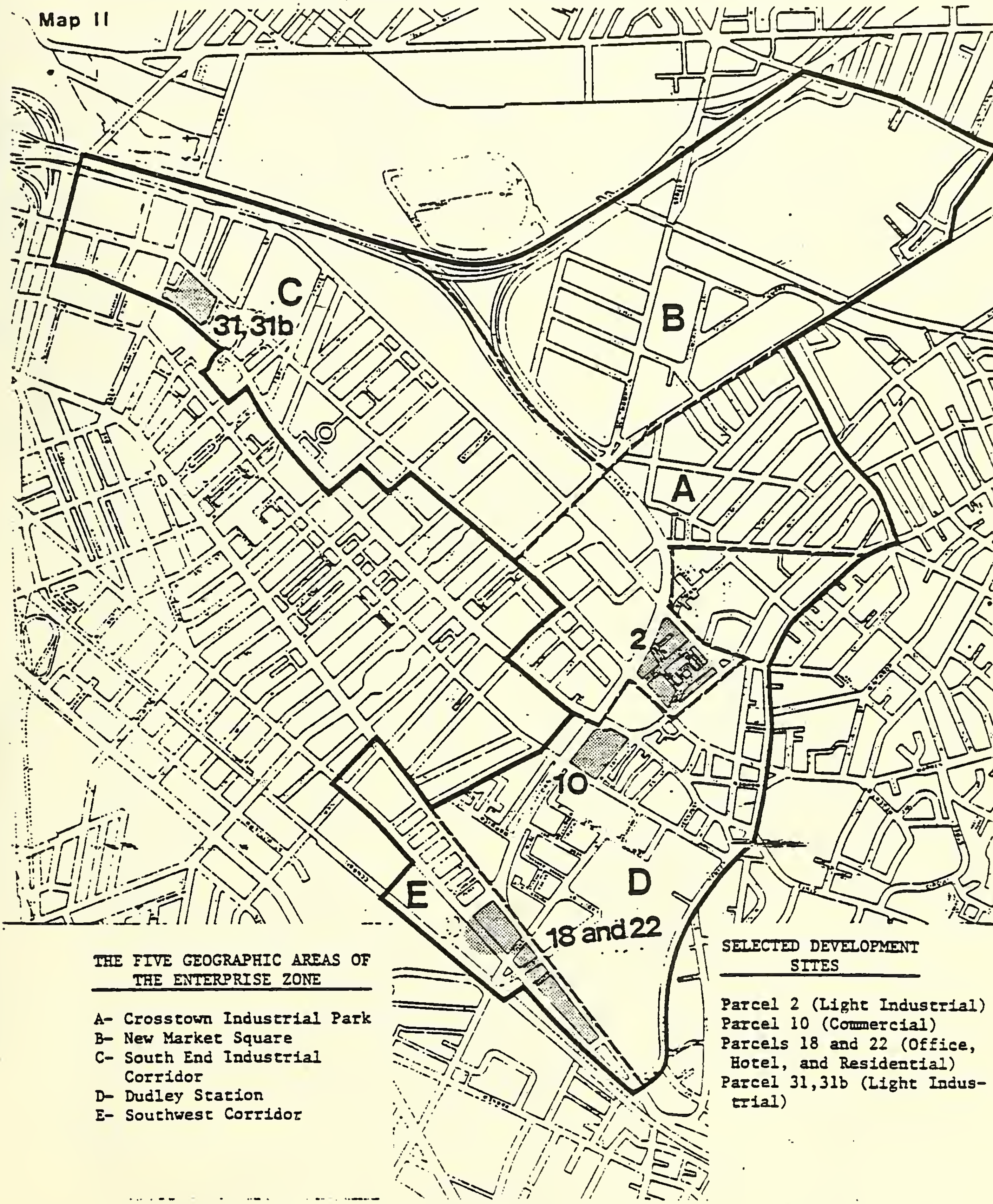
40' CONTAINERS ROTATED IN TO SHAVE PEAKS



AVERY
TREMONT
STREET
ESSEX
HARRISON
AVENUE
PHILLIPS SQ.
KINGSTON
LA GRANGE
BEACH
WASHINGTON
STREET
STAGE EXPANSION
NUTRITION CENTER
WILBUR THEATRE
1040
BOSTON MUSIC HALL
350
TUFTS / N.E.M.C. GARAGE
FLOATING HOSPITAL
T/ N.E.M.C.
ZISKIND RESEARCH LABORATORIES
ST JAMES R.C. CHURCH
HARVARD
BENNET ST
BOSTON DISPENSARY
TUFTS CLINIC
REHABILITATION INSTITUTE
NASSAU STREET
ASH
AUTHORITY
OAK ST
WEST
STREET
TYLER
HUDSON
JOHNNY CT
AVENUE


1978 CAMPUS PLAN
NORTHEASTERN UNIVERSITY
CAMPUS PLAN STUDY
LEGEND
NON-UNIVERSITY BUILDINGS
PROPERTY LINES
GREEN AREAS
N.U. BUILDINGS
HOUSING
ACADEMIC
RECREATION
SERVICE
MASSACHUSETTS AVENUE
HUNTINGTON AVENUE
ST. BOTOLPH STREET
ST. STEPHEN STREET
GAINSBOROUGH STREET
OPERA PLACE
HEMENWAY STREET
FORSYTH STREET
FORSYTH WAY
THE FENWAY
MUSEUM ROAD
LOUIS PRANG STREET
RUGGLES STREET
PARKER STREET
TAVERN ROAD
FIELD STREET
LEON STREET
GREENLEAF STREET
COLUMBUS AVENUE
TREMONT STREET
SYMPHONY HALL
ARENA
NEW ENGLAND CONSERVATORY
UPTOWN GARAGE
YMCA
MUGAR
DODGE
NORTHEASTERN QUADRANGLE
ELL
PEABODY
ROBINSON LOT
ROBINSON
HURTIG
RICHARDS
HAYDEN
CABOT LOT
CABOT
BARLETTA
CHURCHILL
FORSYTH
ANNEX
DANA
HAYDEN LOT
SOUTH LOT
NORTH LOT
STETSON
LIGHT
SPEARE LOT
SPEARE
142-48
SMITH
MELVIN
FORSYTH DENTAL
320-8
WHITE
407
MUSEUM OF FINE ARTS
RUBENSTEIN
KNOWLES
BOUVE LOT
RICHARDS
COCHRAN
UNITED REALTY
PARKER
HILLEL
23-40
LEON LOT
UNITED REALTY LOT
AFRO
TAVERN LOT
FIELD #1 LOT
FIELD #2 LOT
RUGGLES LOT
N-D
WENTWORTH INSTITUTE
GREEK CATHEDRAL
BOSTON TRADE HIGH SCHOOL
MISSION HILL HOUSING
CARTER PLAYGROUND
PARCEL 17x
COLUMBUS LOT

THE ENTERPRISE ZONE: Its Development Areas and Selected Development Sites



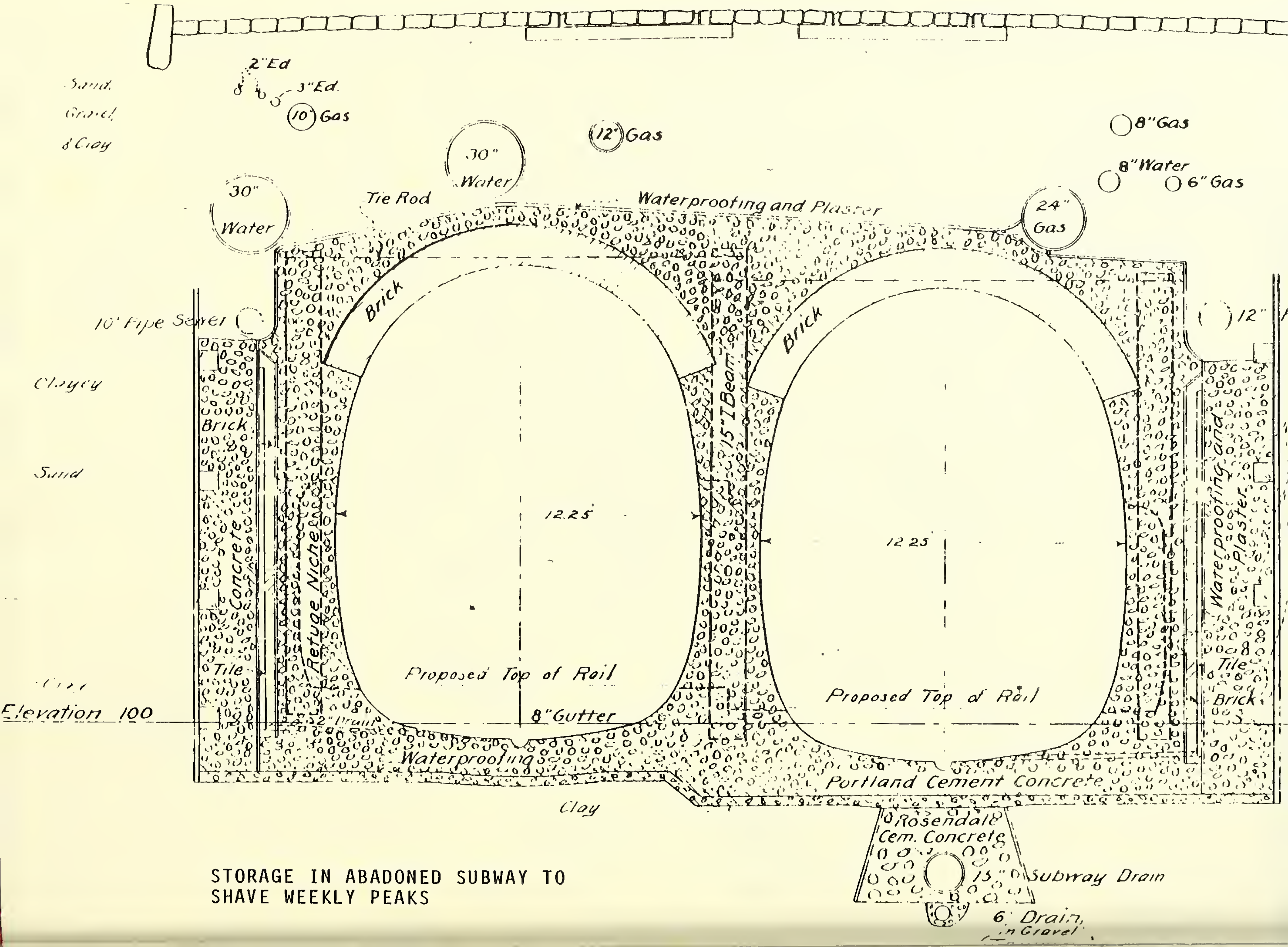
THE FIVE GEOGRAPHIC AREAS OF THE ENTERPRISE ZONE

A- Crosstown Industrial Park
B- New Market Square
C- South End Industrial Corridor
D- Dudley Station
E- Southwest Corridor

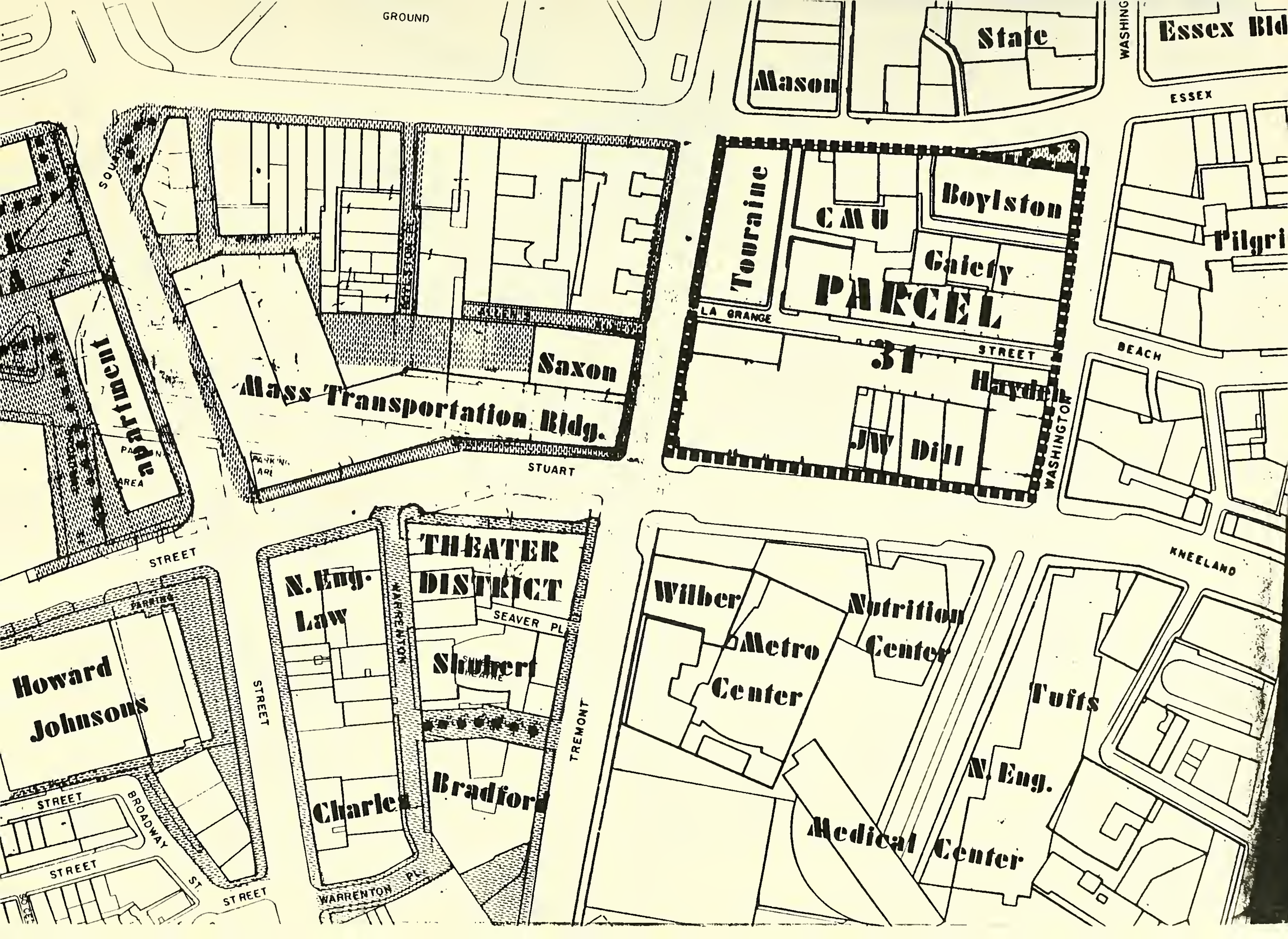
SELECTED DEVELOPMENT SITES

Parcel 2 (Light Industrial)
Parcel 10 (Commercial)
Parcels 18 and 22 (Office, Hotel, and Residential)
Parcel 31,31b (Light Industrial)

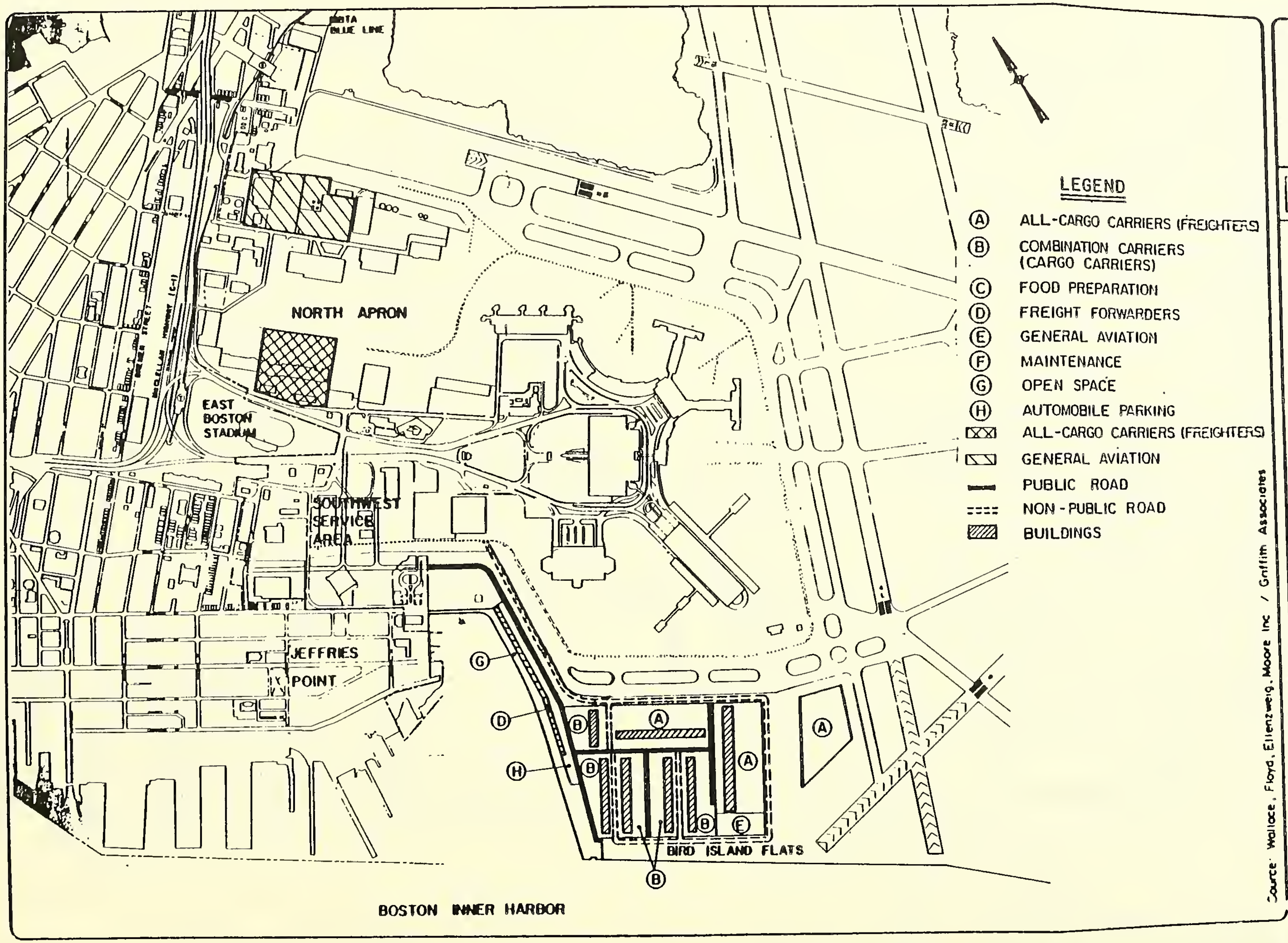
Piled on site



STORAGE IN ABADONED SUBWAY TO
SHAVE WEEKLY PEAKS



GROUND
Mason
State
WASHING
Essex Bld
ESSEX
Touraine
CMU
Boylston
Gaiety
PARCEL
31
Pilgri
LA GRANGE
STREET
BEACH
Hayden
WASHINGTON
JW
Dill
Saxon
Mass Transportation Bldg.
apartment
PARKING AREA
STUART
KNEELAND
THEATER
DISTRICT
SEAVER PL
Shubert
N. Eng.
Law
WARRENTON
Wilber
Metro
Center
Nutrition
Center
Tufts
N. Eng.
Medical Center
Howard
Johnsons
PARKING
STREET
STREET
TREMONT
Bradford
Charles
WARRENTON PL
STREET
BROADWAY
ST.
STREET
STREET



Source: Wallace, Floyd, Ellenzweig, Moore Inc / Griffith Associates

BOSTON - LOGAN INTERNATIONAL AIRPORT
BIRD ISLAND FLATS
EIR / EIS

HIGH INTENSITY CARGO WITHOUT GENERAL AVIATION

I-A

FIGURE 32-4

HOT AND COLD STORAGE IN UNDERGROUND MUD
VIA HEAT PIPES

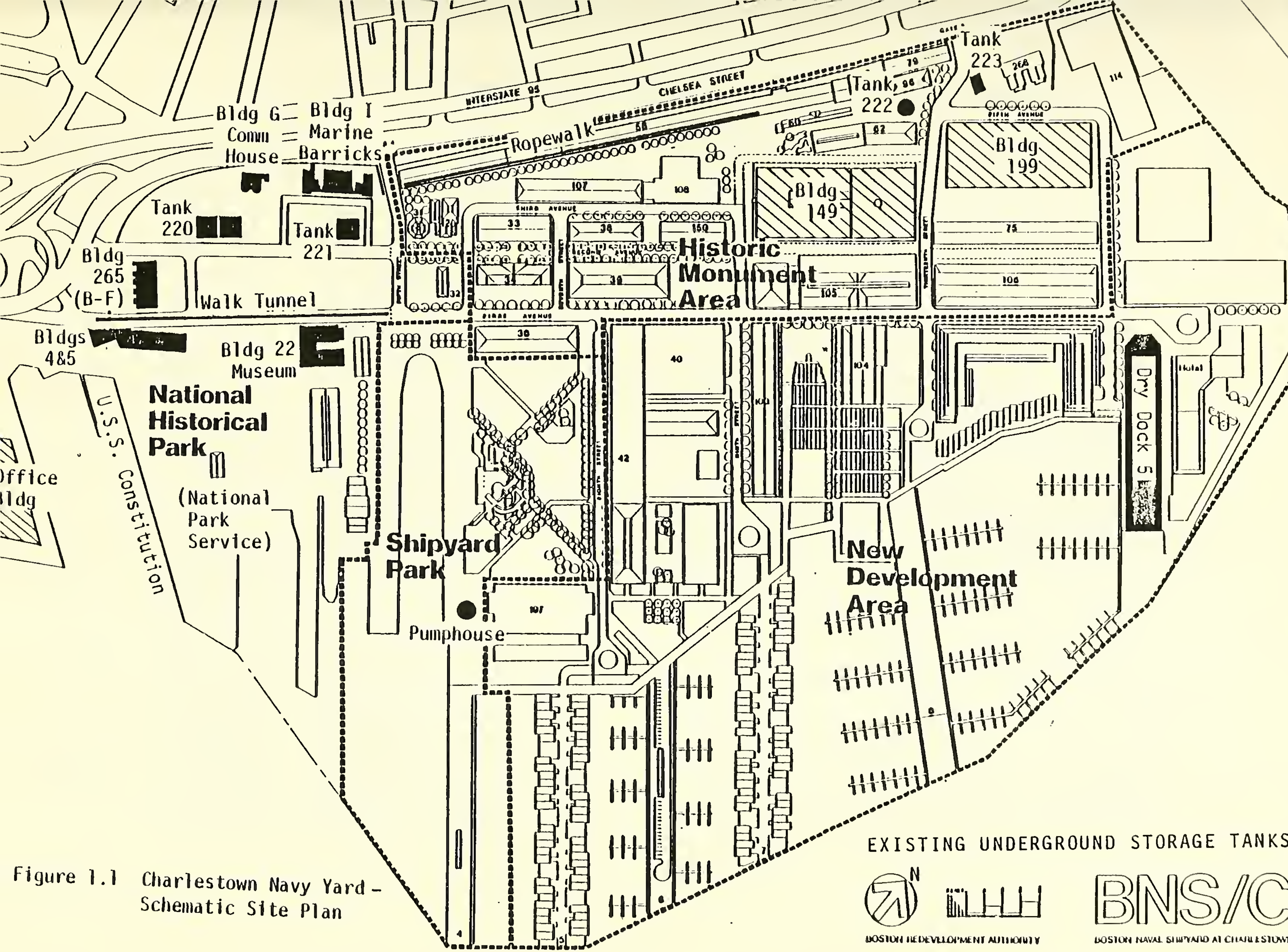


Figure 1.1 Charlestown Navy Yard - Schematic Site Plan

I. Site Information

The Phase II development site which consists of two parcels encompassing approximately 50 acres is presently owned by the Boston Housing Authority and the City of Boston Public Facilities Department (see Map 3).

The BHA parcel of 37.7 uplands acres is the site of the Columbia Point housing project which consists of three 1-story, non-residential buildings and 1,504 housing units in 15 seven-story and 12 three-story buildings. However, only 25% of the existing units are currently occupied. Nine of the seven-story buildings and one three-story building are completely vacant and boarded and three others are partially boarded. The fourteen remaining residential buildings are occupied by approximately 1,500 people (360 families and 40 elderly or handicapped residents). An additional seventy-five apartments are occupied by 12 social service agencies.

The low-rise buildings are generally located along Mt. Vernon Street and the westerly portion of the site. The mid-rise buildings form a dense central core and continue to the easterly edge. The low-rise buildings and central mid-rise buildings, if occupied, house predominantly families. The mid-rise buildings on the eastern end of the development, Buildings #26 and #27, are partially occupied by the 40 elderly or handicapped residents (see Appendix A - Building Number Plan).

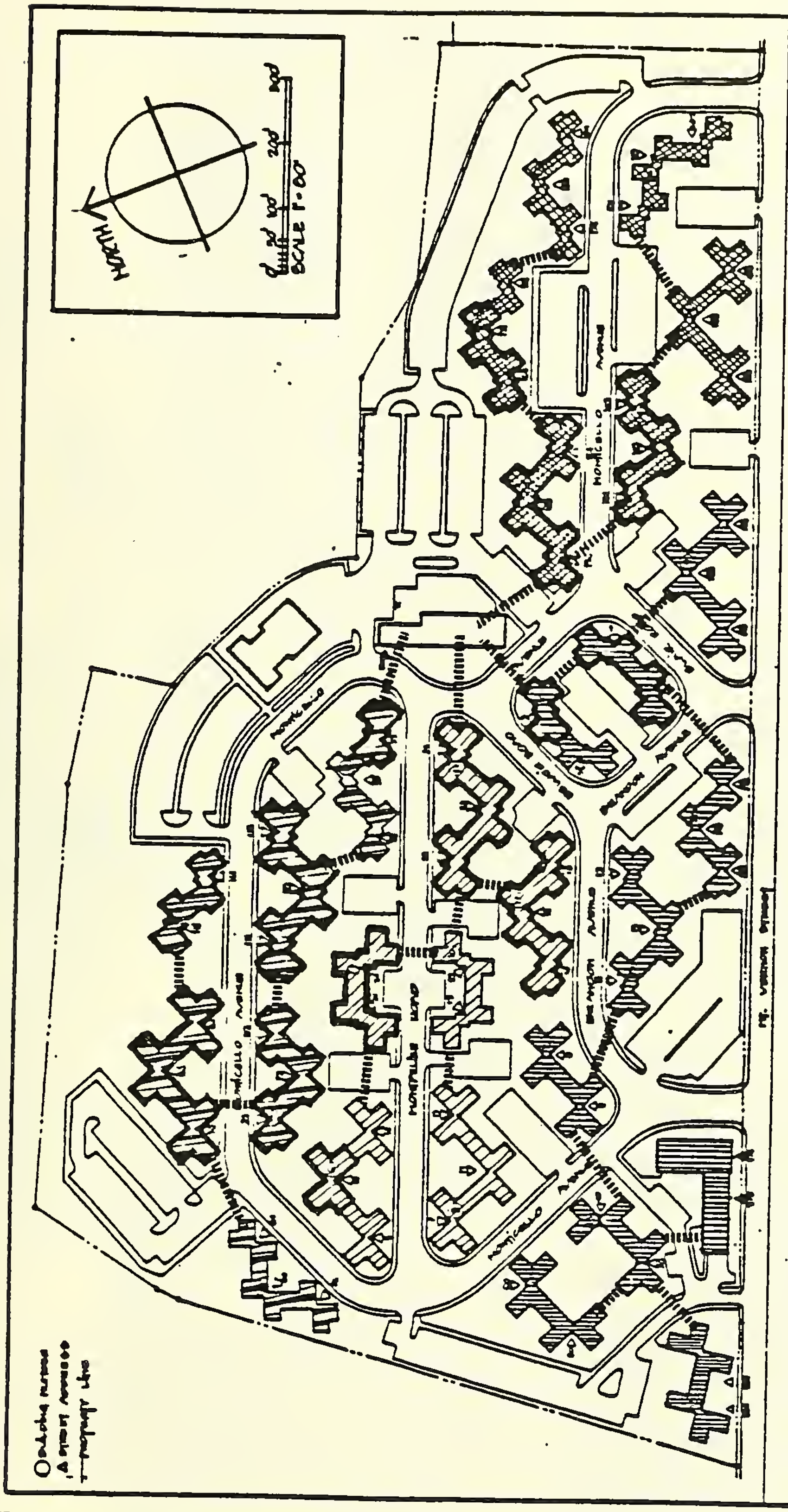
The buildings are all of reinforced concrete frame with masonry walls and brick exterior. They are linked by a city street system and are served by twenty-three at-grade parking areas with a total of 1,150 spaces.

An administrative building located on Mt. Vernon Street, containing office space, an assembly hall and a day-care center is one of the three non-residential project structures. The other two buildings are a City of Boston Parks Department recreation building located on the eastern edge of the site abutting the city-owned park, and a nearby steam-heat oil-fired generation plant with four boilers that were renovated in 1978. All buildings on the site, except the recreation building, are served by the central heating plant via four underground loops. The distribution lines need substantial repair.

The City of Boston parcel of 13.5 uplands acres is presently the site of a waterfront park serving the housing development. Tennis and basketball courts, baseball fields and a tot-lot were developed for the residents on the western portion, but are not in good condition due to poor maintenance. The eastern portion of this parcel is essentially vacant.

MAP 9

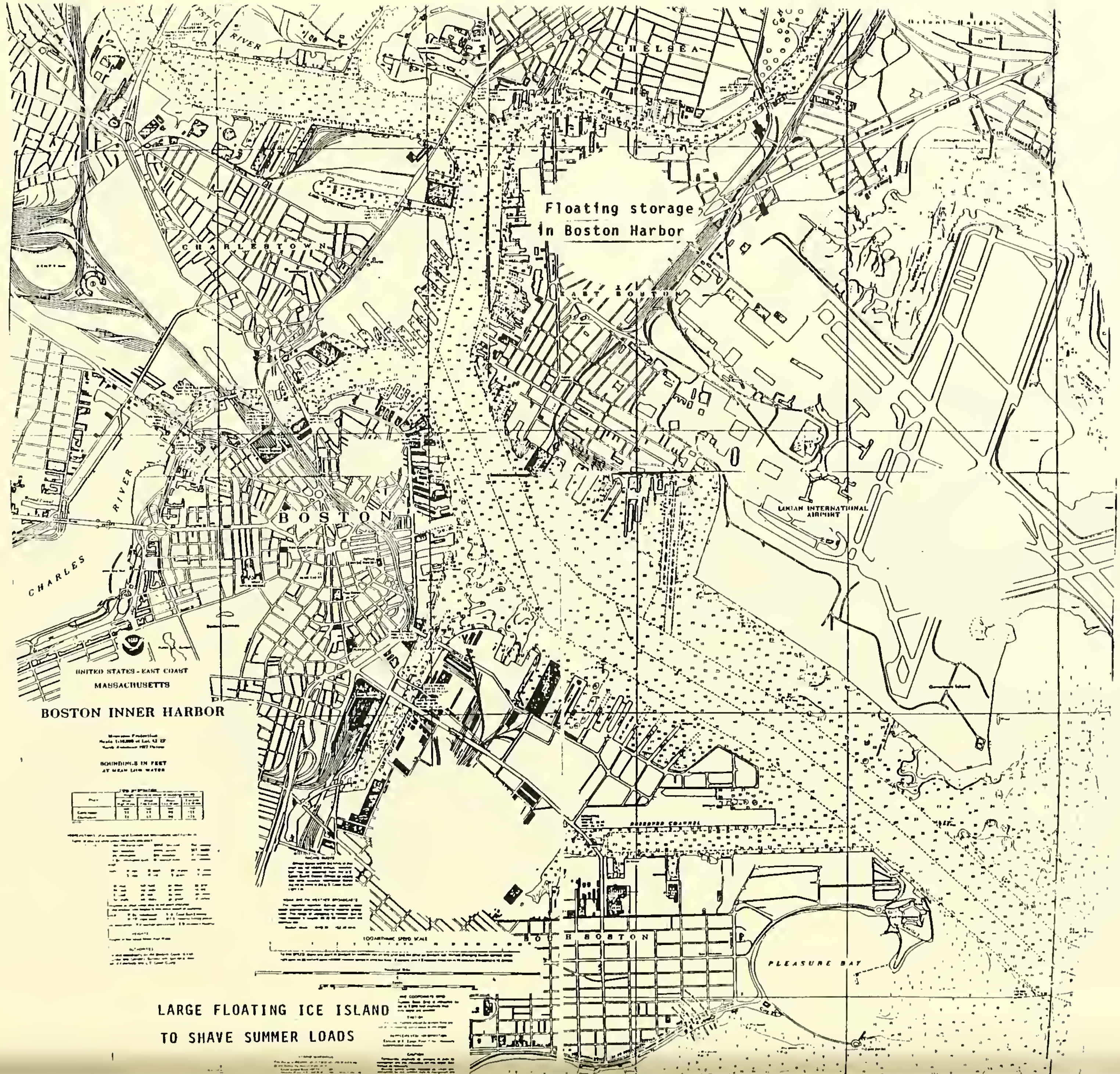
EXISTING UTILITIES
(Heating)



EXISTING UTILITIES

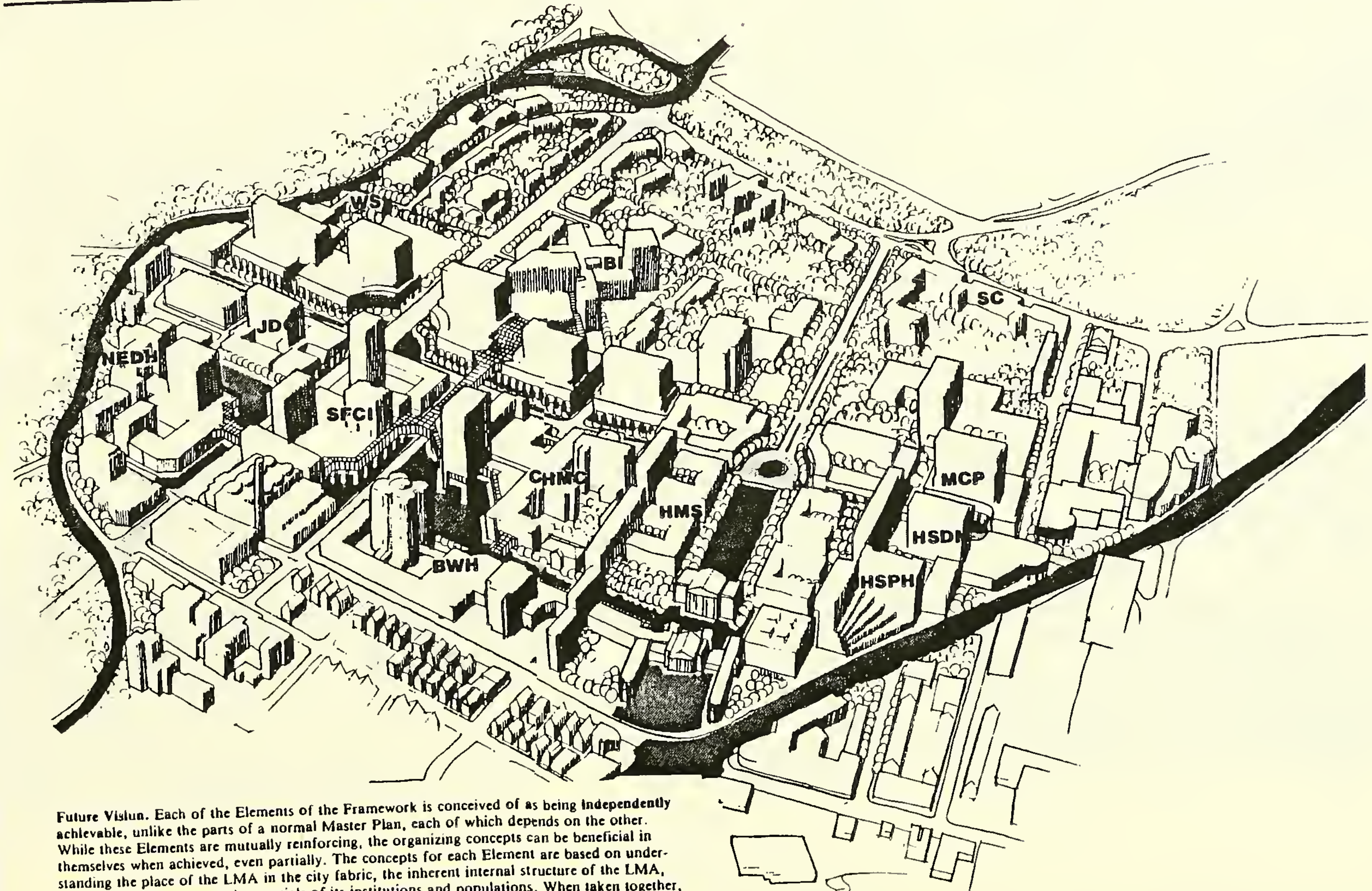
- Heating System
- "
- "
- "
- Mothballed Structures
- Heating pipes
- SNOW BOX IN VACANT BUILDING

COLUMBIA POINT HOUSING PROJECT



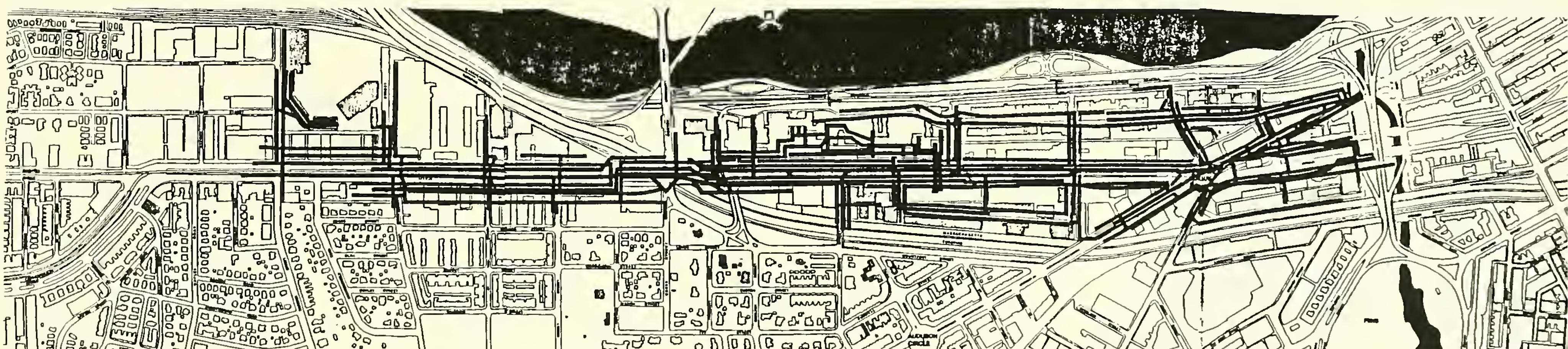
Floating storage
in Boston Harbor
CHELSEA
MYSTIC RIVER
CHARLESTOWN
EAST BOSTON
LOGAN INTERNATIONAL AIRPORT
BOSTON
CHARLES RIVER
SOUTH BOSTON
PLEASURE BAY
UNITED STATES - EAST COAST
MASSACHUSETTS
BOSTON INNER HARBOR
SOUNDINGS IN FEET AT MEAN LOW WATER
LARGE FLOATING ICE ISLAND
TO SHAVE SUMMER LOADS

Barry's Quarry SNOW FROM CITY STREETS TO BARRY'S QUARRY



Future Vision. Each of the Elements of the Framework is conceived of as being independently achievable, unlike the parts of a normal Master Plan, each of which depends on the other. While these Elements are mutually reinforcing, the organizing concepts can be beneficial in themselves when achieved, even partially. The concepts for each Element are based on understanding the place of the LMA in the city fabric, the inherent internal structure of the LMA, and the varied interests and potentials of its institutions and populations. When taken together, these Elements embody a long-range vision of a grander environmental future for the Longwood Medical Area—a backdrop against which shorter-term Action Projects can be put into perspective. This future vision must be understood as a provisional concept which reflects current perceptions, but which will be continuously revised and improved as goals change and potentials develop.

MAP 20

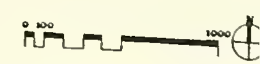


UTILITY PLAN 2

Electricity
Gas
Telephone
University Steam
University Electricity

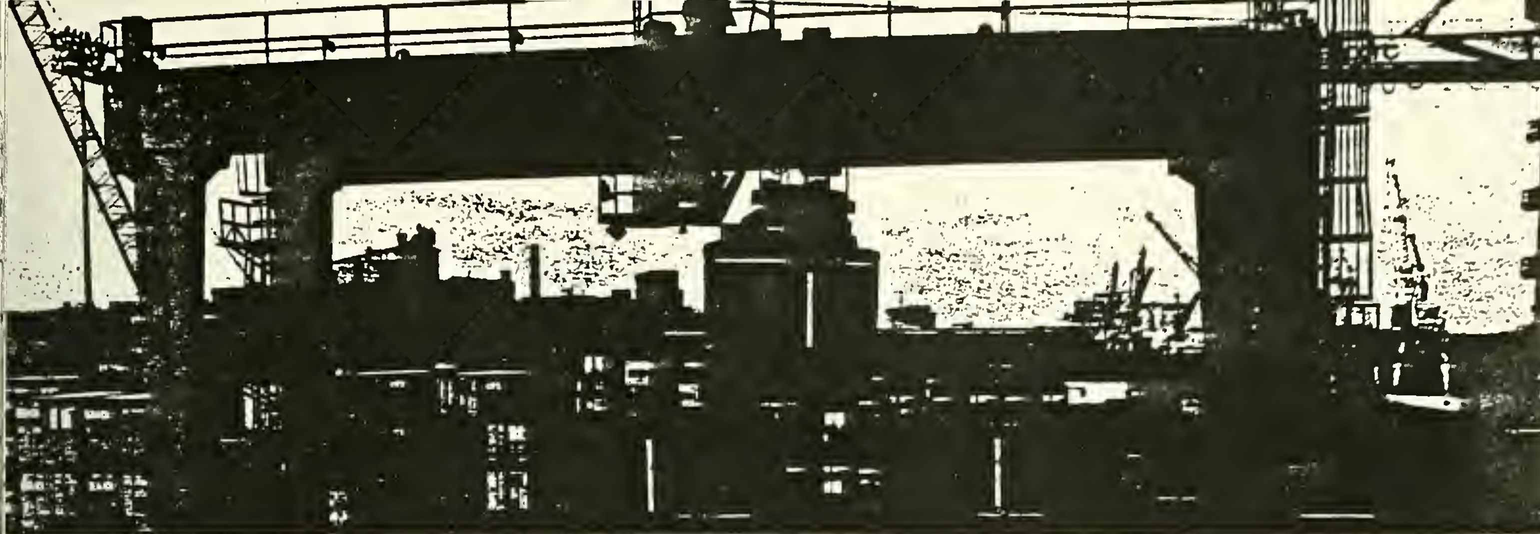
BOSTON UNIVERSITY
CHARLES RIVER CAMPUS DEVELOPMENT PLAN

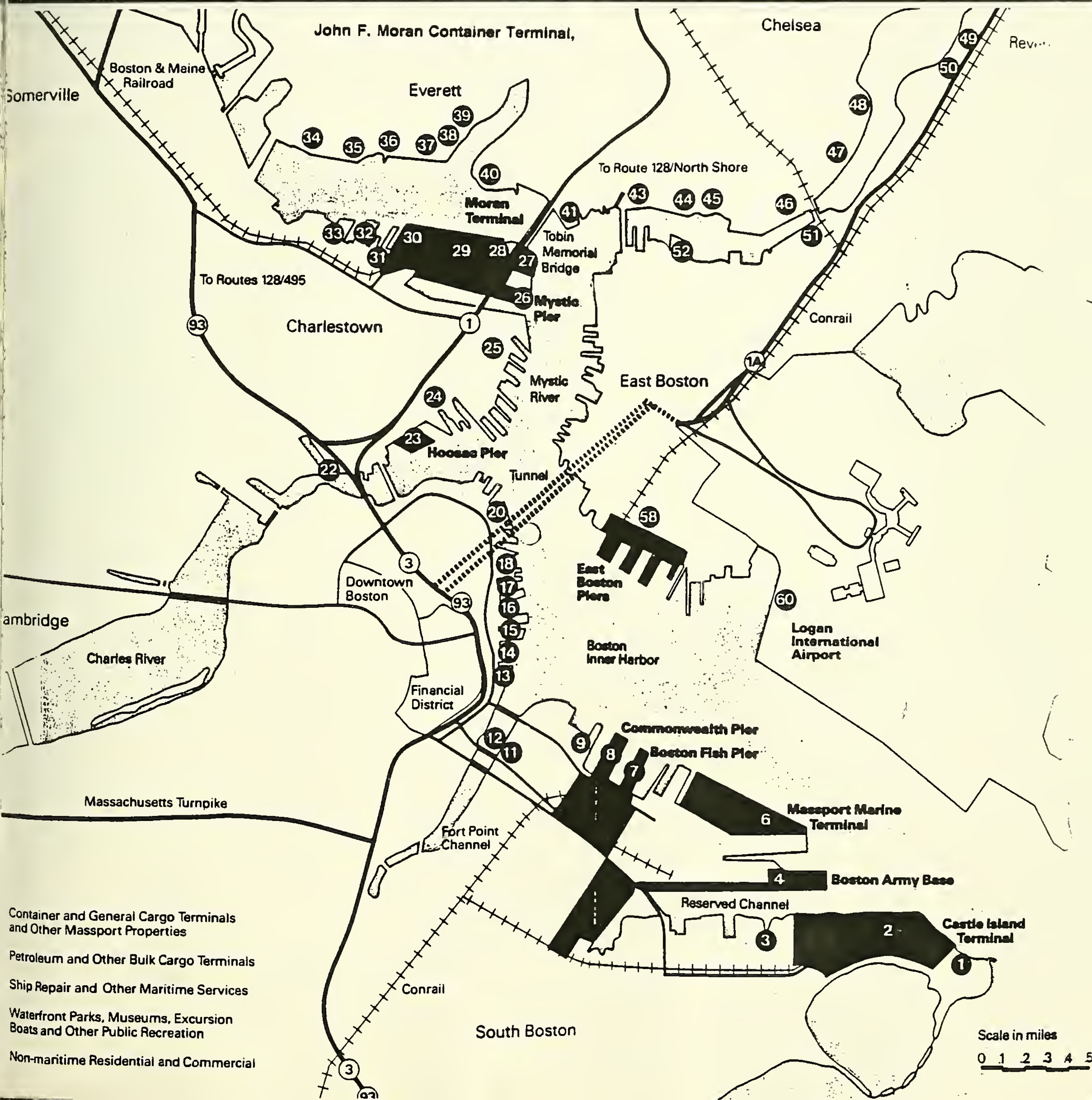
Boston University Campus Development Committee
prepared by Jung/Brannen Associates, Inc. Architects



STREET
SUMMER
HAWLEY
STREET
ARCH
OTIS
PLACE
STREET
STREET
STREET
KINGSTON
BEDFORD
STREET
Lafayette
Place
KINGSTON
CHAUNCY
HAYWARD
PL.
HARRISON
STREET
EDIN' ORO
OXFORD
PHILLIPS
SQ
WASHINGTON
ESSEX

STREET
SUMMER
HAWLEY
STREET
ARCH
OTIS
PLACE
STREET
STREET
KINGSTON
STREET
BEDFORD
STREET
Lafayette Place
KINGSTON
CHAUNCY
PL.
HAYWARD
HARRISON
STREET
EDIN'-ORO
OXFORD
PHILLIPS SQ
WASHINGTON
ESSEX





John F. Moran Container Terminal,
Chelsea
Boston & Maine Railroad
Somerville
Everett
34
35
36
37
38
39
40
To Route 128/North Shore
41
43
44
45
46
47
48
49
50
51
52
Moran Terminal
33
32
31
30
29
28
27
Tobin Memorial Bridge
To Routes 128/495
26
Mystic Pier
93
Charlestown
1
Conrail
25
Mystic River
East Boston
1A
24
23
Hoosac Pier
22
Tunnel
20
58
3
Downtown Boston
18
17
16
15
14
13
East Boston Piers
60
93
Cambridge
Charles River
Boston Inner Harbor
Logan International Airport
Financial District
Commonwealth Pier
9
8
12
11
Boston Fish Pier
7
Massachusetts Turnpike
Massport Marine Terminal
6
Fort Point Channel
4
Boston Army Base
Reserved Channel
3
2
Castle Island Terminal
1
Container and General Cargo Terminals and Other Massport Properties
Petroleum and Other Bulk Cargo Terminals
Ship Repair and Other Maritime Services
Waterfront Parks, Museums, Excursion Boats and Other Public Recreation
Non-maritime Residential and Commercial
Conrail
South Boston
Scale in miles
0 1 2 3 4 5
3
93

OPPORTUNITIES FOR EXPORT

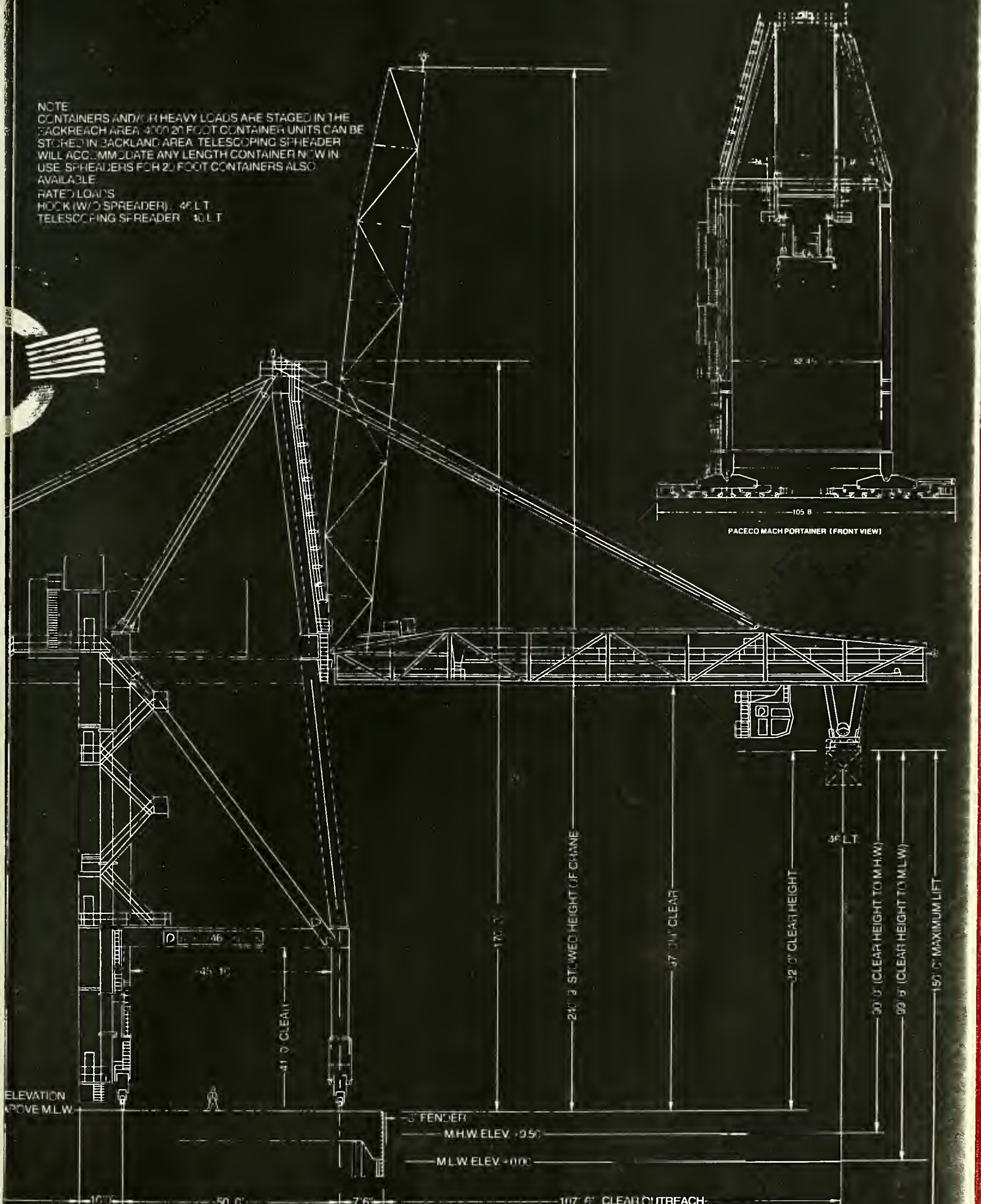
BYRON COOK 482-2930
RENO MARCONI 482-2930.

BULK SHIPS
DRY CARGO (SUGAR, GYPSUM)
LIQUID CARGO (OIL, WINE, BEAR)

CONTAINERS.
COST $20,000 APIECE
REFRIGERATOR CONTAINERS COST MORE.

BOATS DON'T KNOW DESTINATION UNTIL AFTER THEY HAVE LEFT PORT.

LARGEST BULK EXPORT FROM BOSTON IS SCRAP METAL
MANY SHIPS AVOID BOSTON BECAUSE NOTHING TO TAKE BACK.
GO TO NYC - LARGEST PORT IN WORLD.
HOUSTAN IS #2 & NEW ORLEANS #3
LOTS OF COAL LEAVES FROM NORFOLK.
MOST PRODUCE FROM MIAMI IS TRUCKED
BEER, WINE, & CUTTING TOOLS BIG IMPORTS FROM EUROPE
SUGAR FROM AUSTRALIA, INDIA, & CENTRAL AMERICA.



PACECO MACH PORTAINER (FRONT VIEW)

PACECO MACH PORTAINER (SIDE VIEW)
46 L.T